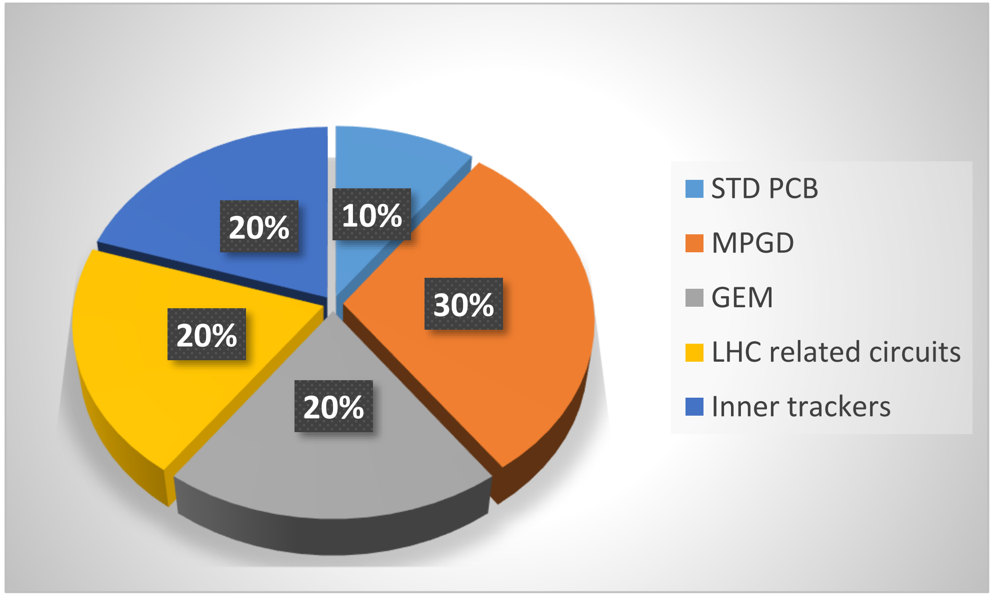
CERN MPT workshop
(Micro Pattern Technologies)

MPT activity

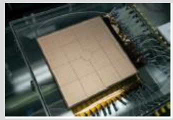


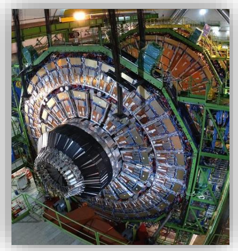
-20 persons.
-1400m2.
-100m2 clean room.
-Top class environnement protection:
    -Waste water treatment plant.
    -Large scrubbers for fume cleaning.
    -Fire extinguisment water containment.

PCB: Printed Circuit Board
MPGD : Micro Pattern Gas Detectors
    -GEM : Gas Electron Multiplier
    -Micromegas or uMegas or MM: Micro mesh gaseous detector
    -uRwell: Micro Resistive Well detectors

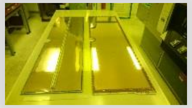
Examples of MPT activities

GEM :



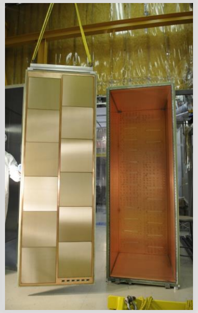


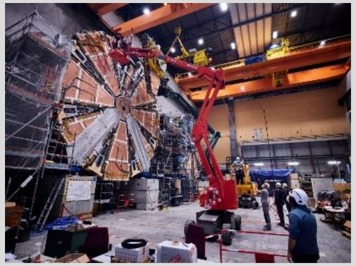
Compass
CMS GEM GE1/1
CMS GEM GE2/1
ALICE TPC GEM
CBM GEM for Fair
BM@N (Baryonic Matter at the Nuclotron Dubna)
Low material budget detectors (Hampton university)
Kloe
Totem
LHC-B
Phoenix TPC (Brookhaven)
SBS tracker (Jefferson Lab)
EIC tracking detectors (Jefferson Lab)
Etc…



Micromegas

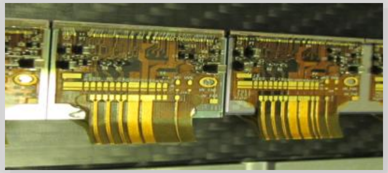
ILC Calorimeter
Minos TPC
T2K
ATLAS NSW
Cast
Panda X uBulk detectors
TrexDM uBulk detectors
TPC's for Nuclear physics
Beam for School
T2K upgrade
Clas12
Scanpyramid
Etc…

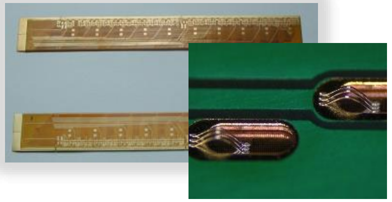




Inner trackers

ALICE Inner tracker Al Bus
Phoenix TPC AL bus
ATLAS IBL
ATLAS ITK
LHCB data flexes





LHC

Quench heaters
Power Thick film resistors
Magnetic sensors calibration
Flexible heaters
Diamond beam monitoring detectors
Many Chemical milling
RF Fingers

FSU Experts

-Photolithography (down to 30um line/space):
  -Resist Lamination, spraying.
  -UV exposure → LDI , STD , large , scanner.
  -Resist Devellopment.
  -Resist Stripping.

-Chemical etching:
  -metals :Cu,Al,Ni,Au,Ti,W etc..

-Adam Drozd
-Guillaume Button
-Christophe Ferreira De Oliveira
-Pawel Dubert

-CNC Drilling/milling.

-Katia Jauregui

Adam Drozd FSU team leader
Benilde Martins Administration

-Galvanic and chemical plating:
  -Cu, Ni, Au, In.

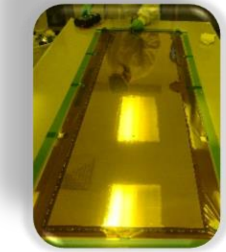
-Xavier Thery

-Vacuum press gluing.

-Jorge Penedo

-Optical & Electrical tests

-Elise Pechaud



-Detectors production

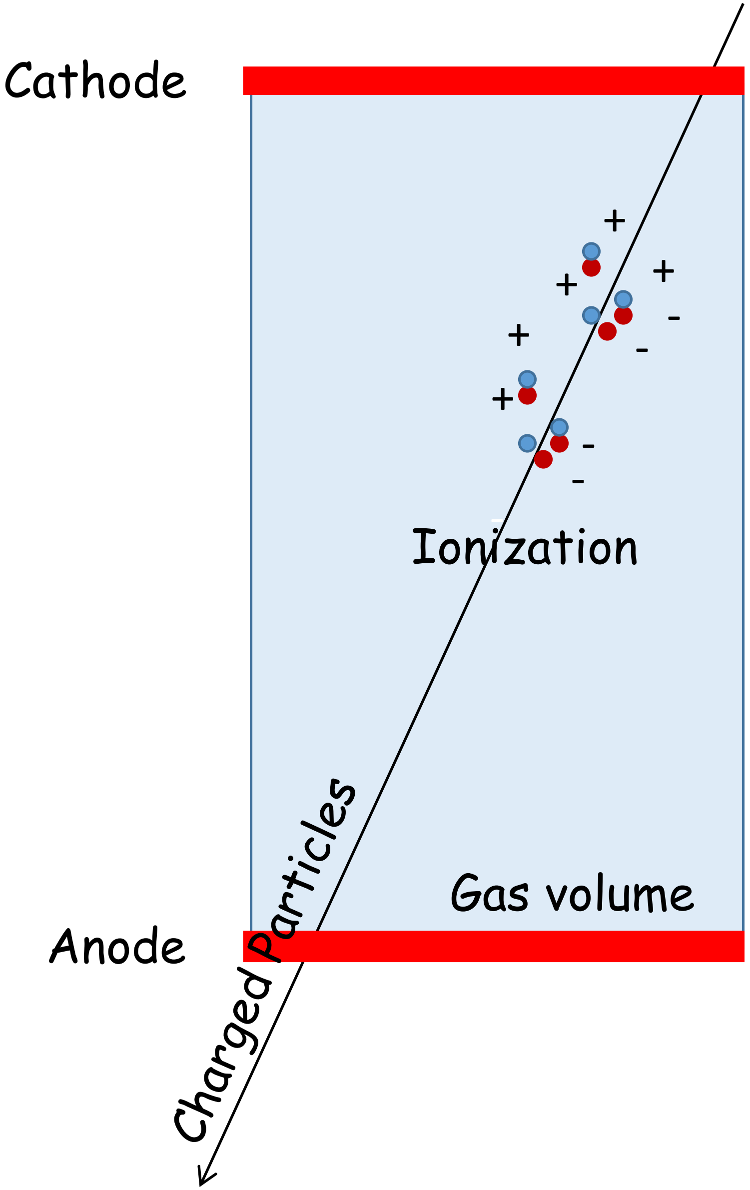
-Zafer Budun
-Paul N'Guyen
-Patrick Ferreira De Oliveira
-Ercan Budun

CERN Staff experts

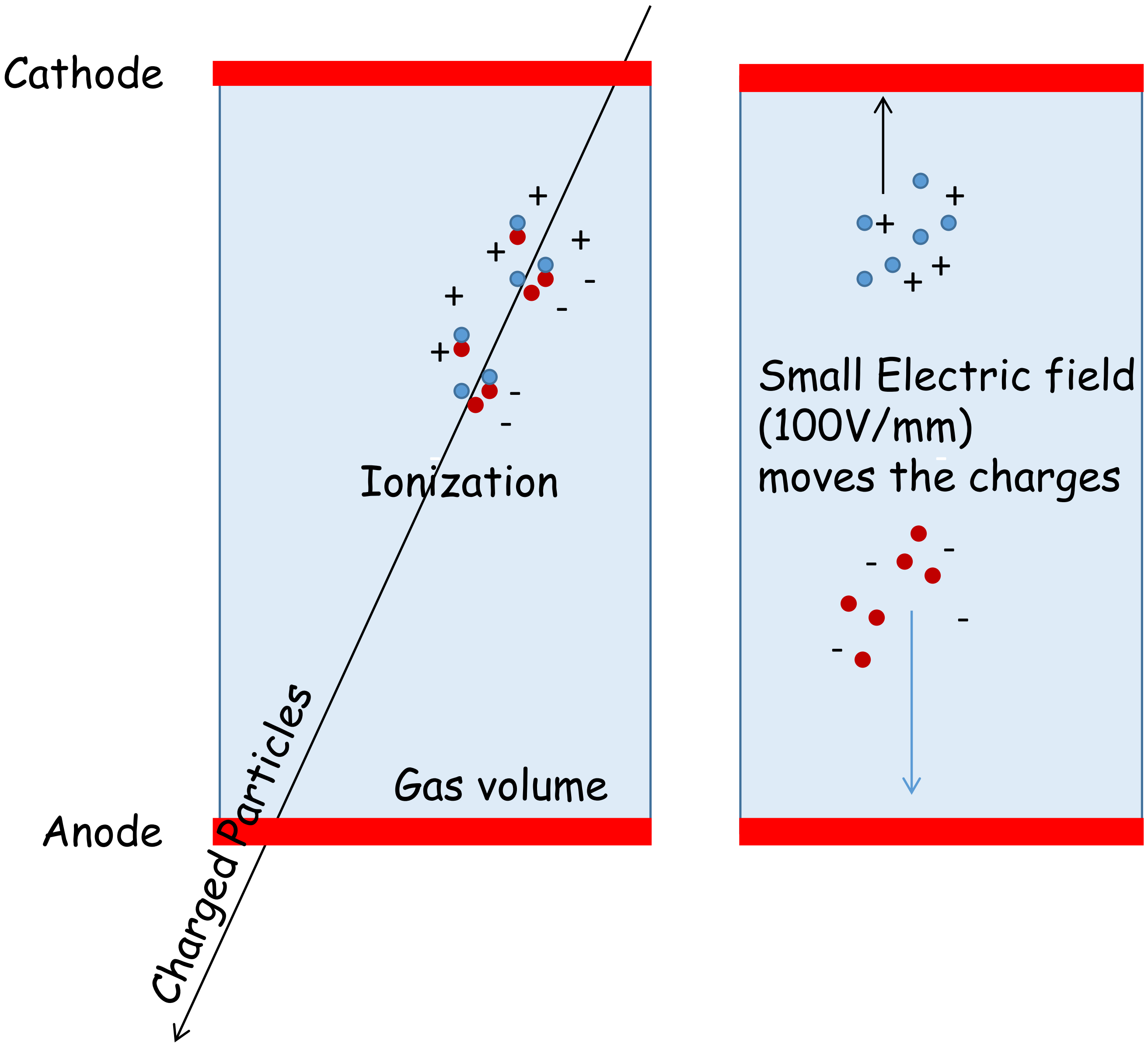
-Design	Bertrand Mehl
- Gazeous Detectors R&D	Alexis Rodrigues Olivier Pizzirusso Antonio Teixeira
-Thin Film , Thick Film R&D	Antonio Teixeira
-Vacuum deposition R&D	Serge Ferry
-Chemical analysis	Alexandra Gris

Introduction to MPGD detectors

Gaseous Detectors principle

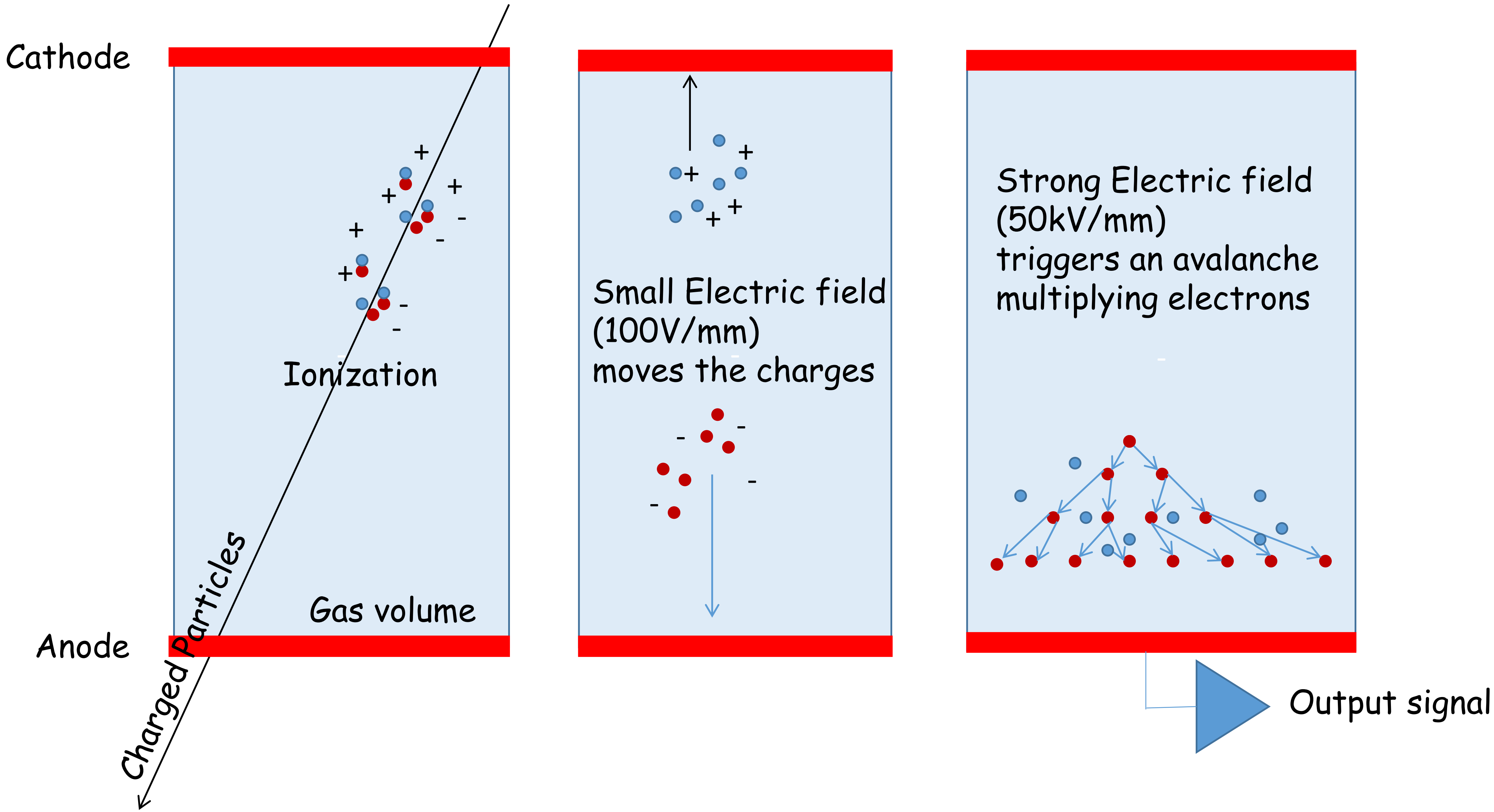


Gaseous Detectors principle



Small Electric field (100V/mm) moves the charges

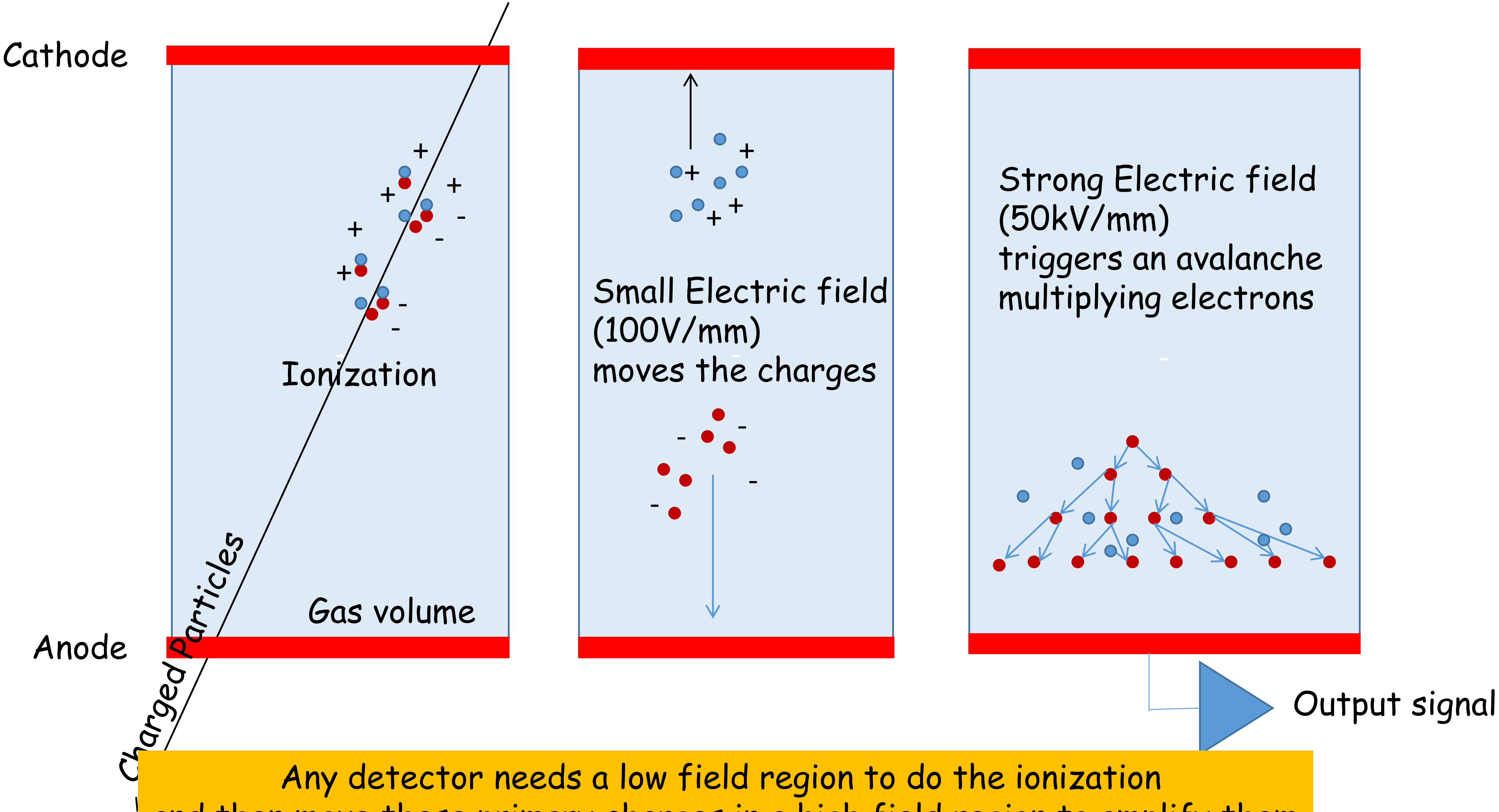
Gaseous Detectors principle



Small Electric field (100V/mm) moves the charges

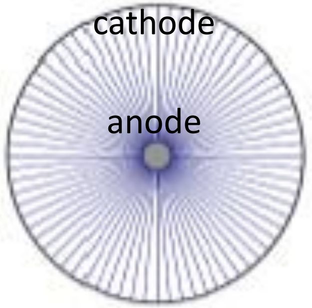
Strong Electric field (50kV/mm) triggers an avalanche multiplying electrons

Gaseous Detectors principle

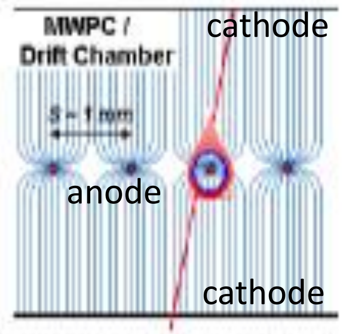


Any detector needs a low field region to do the ionization
and then move these primary charges in a high field region to amplify them

Different ways to get these 2 fields

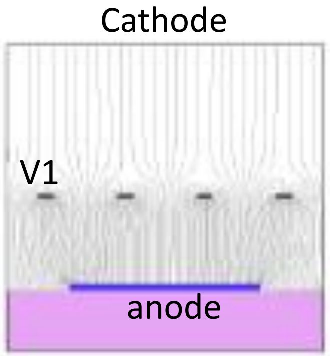


wire

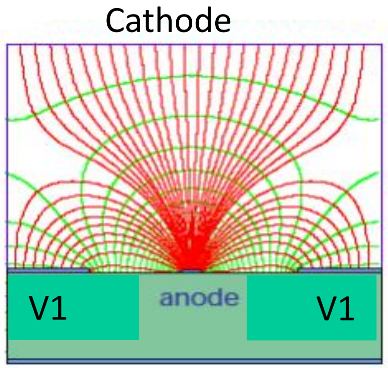


mwpc

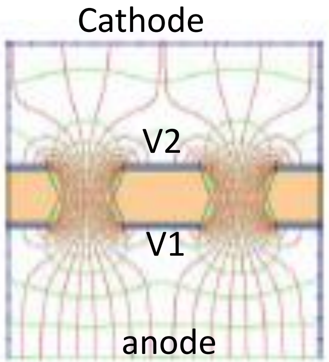
The 2 regions are naturally obtained because the field increases close to the small Anodes wires



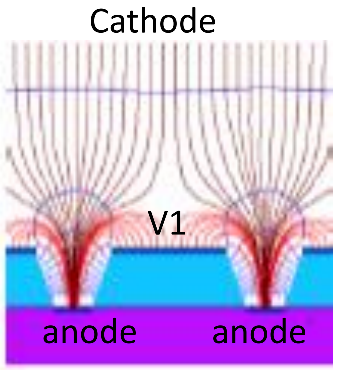
parallel plate



strip



hole



groove/well

The 2 regions are obtained by adding electrodes and 3D structures

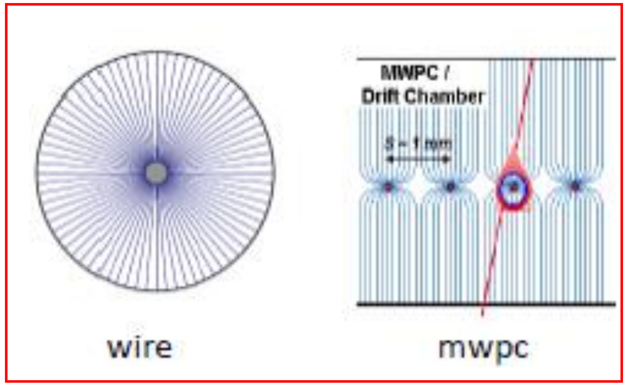
Why MPGD ?

Wire chambers

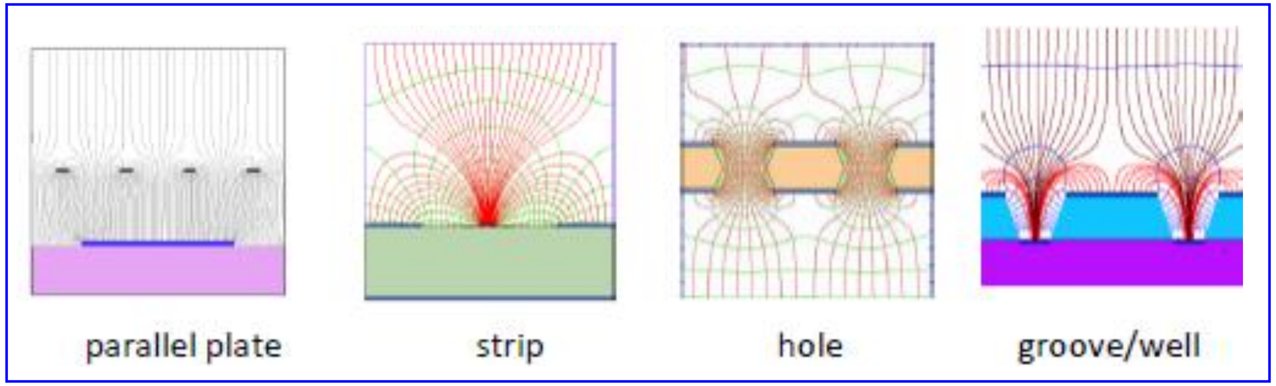
- slow ion evacuation
- Limited read out granularity

Micro Pattern Gas Detectors

- Faster ion evacuation
- Higher spatial resolution
- Reduced multiplication region size



wire mwpc

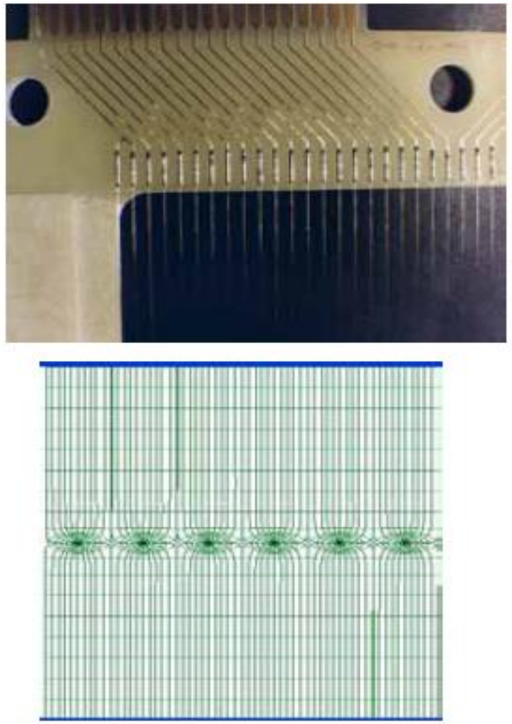


parallel plate strip hole groove/well

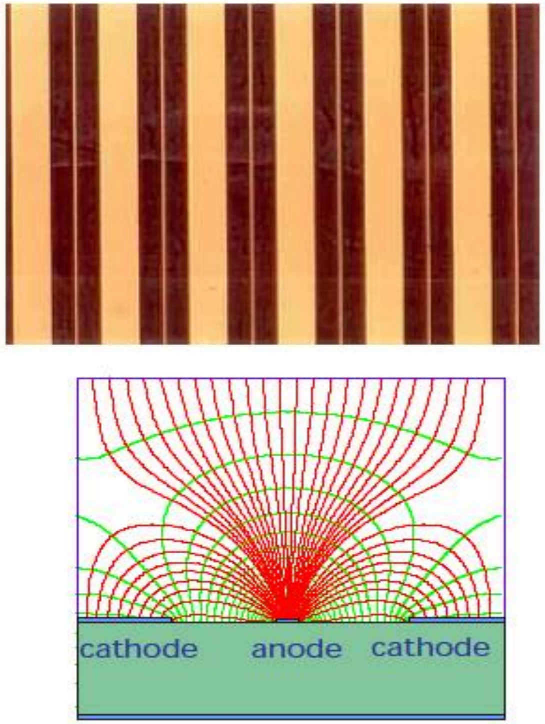
MPGDs have detecting cells 10 times smaller than wire chambers structure
→ photolithographic technics

First MPGD → Micro Strip Gas Chamber (MSGC)

MWPC



MSGC



A. Oed
Nucl. Instr. and Meth. A263
(1988) 351.

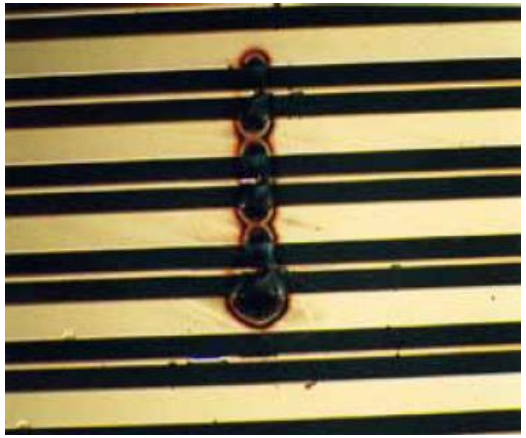
Pitch limited to 1 to 2mm due to mechanical and electrostatic forces.

Glass substrate with anode strips of 10 um with a pitch of 200 µm.
More simple than a wire Chamber.

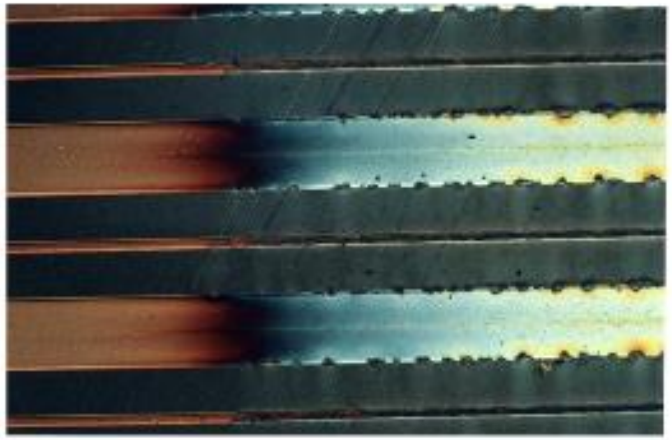
RESULT:

Spatial resolution ~50µm
Rate capability ~10^6 Hz/mm2

But as everybody knows there is always a problem



Spark damages coming
with heavy ionizing particles
→Unstoppable erosion of
electrodes.
Too difficult to solve



Aging
→Creation of dendritic deposits
reducing the gain.
Same problem in Wire chambers
Also difficult to solve

Came a period where many different structures were tested by many labs to overcome such defects

Micro Gap Chambers

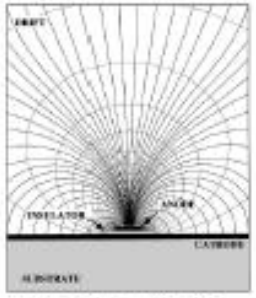


Figure 3 [illegible]

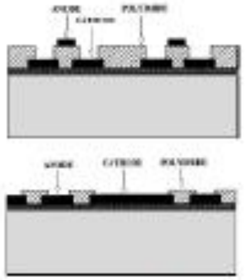


Figure 25 Two variants of small-gap chambers, using thick polyimide ridges to prevent the onset of discharges.

Angelini F, et al. Nucl. Instrum. Methods A335:69 (1993)

Micro Gap Wire Chamber

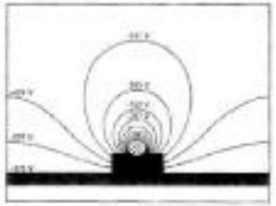
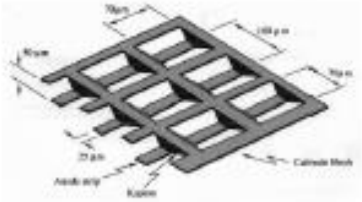


Figure 2.27 Scheme of a MGWC with equipotential and field lines. The circle filled with lines is the section of an anode wire [CHRISTOPHEL1997].

E. Christophel et al, Nucl. Instr. and Meth, vol 398 (1997) 195

Micro Wire Chamber



B. Adeva et al., Nucl. Instr. And Meth. A435 (1999) 402

MicroDot

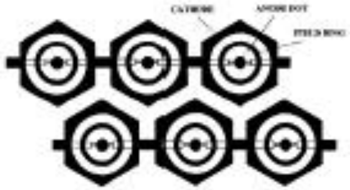
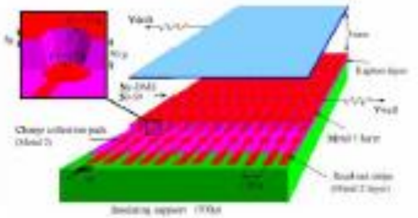


Figure 26 Schematics of the microdot chambers. A pattern of metallic anode dots surrounded by field and cathode electrodes is implemented on an insulating substrate, using microelectronics technology. Anodes are interconnected for readout.

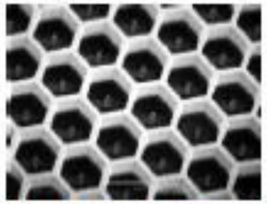
Biagi SF, Jones TJ. Nucl. Instrum. Methods A361:72 (1995)

MicroWELL



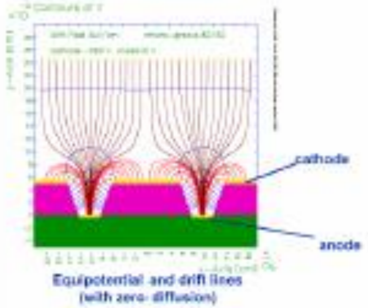
R. Bellazziniet al
Nucl. Instr. and Meth.
A423(1999)125

MicroPin



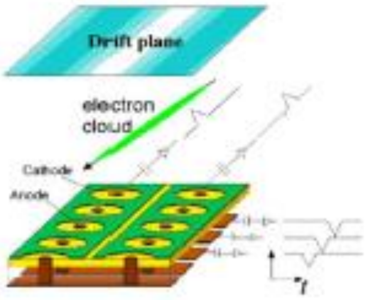
P. Rehak et al., IEEE Nucl. Sci. Symposium seattle 1999

MicroGroove



R. Bellazzini et al
Nucl. Instr. and Meth. A424(1999)444

μPIC

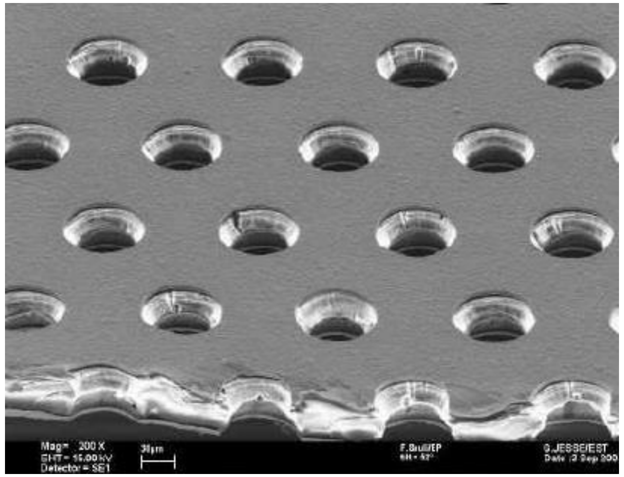


AND MANY OTHERS ….

Ochi et al NIMA471(2001)264

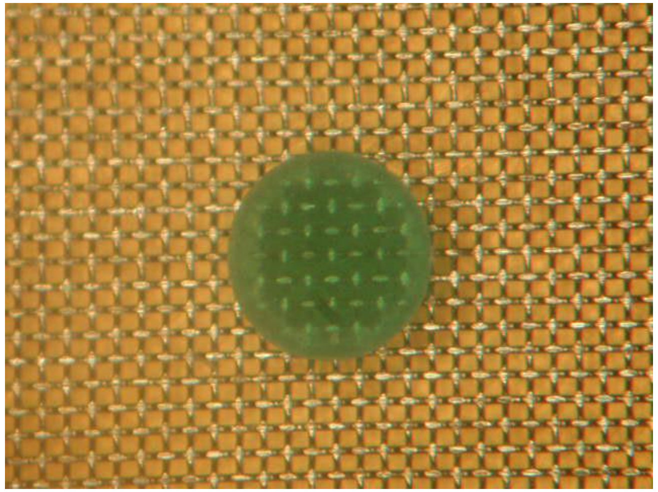
Nowadays, I think we can consider that the winners are:

GEM family



- GEM
- Thick-GEM
- uRwell

Micromegas family



- Micromegas
- Resistive Micromegas
- uBulk

Nowadays, I think we can consider that the winners are:

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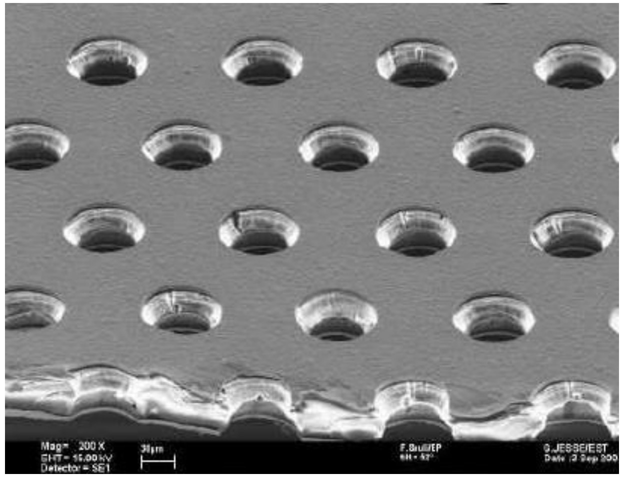
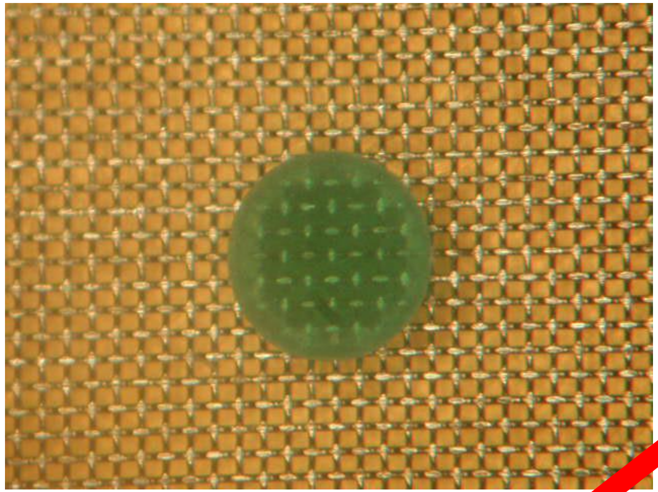


- GEM
- Thick-GEM
- uRwell

Micromegas family

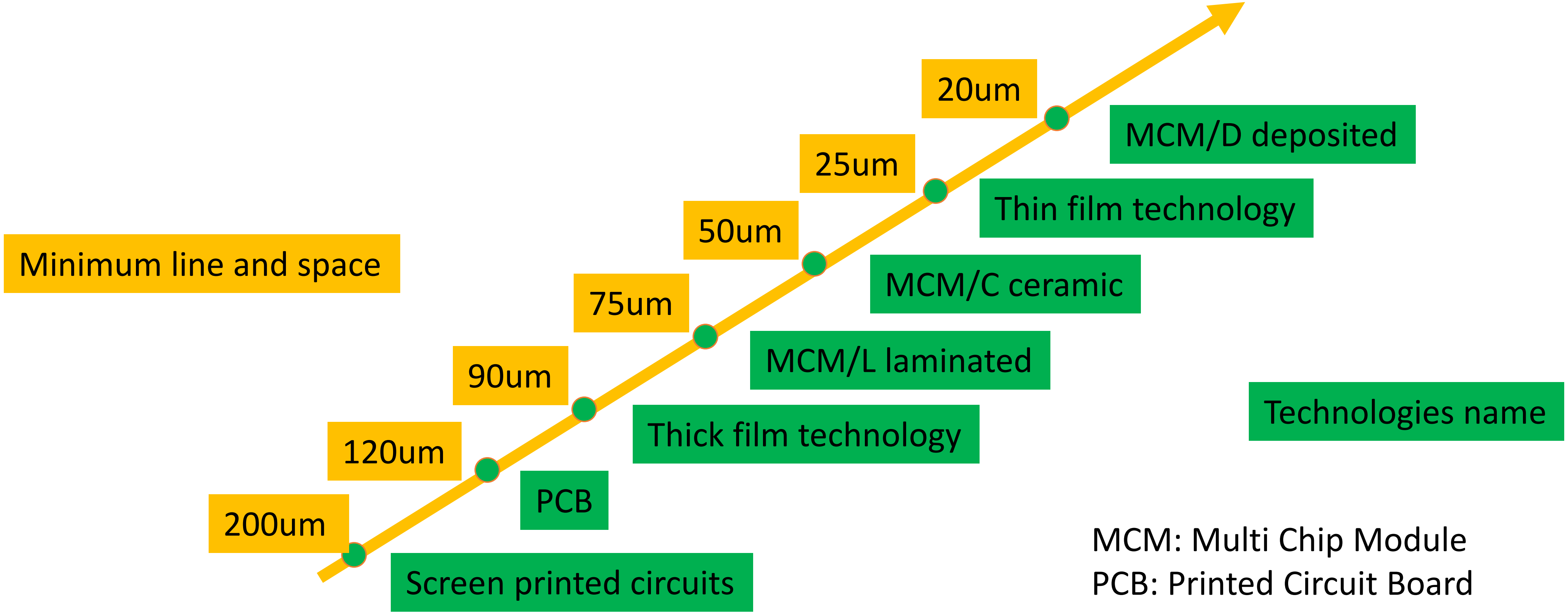


- Micromegas
- Resistive Micromegas
- uBulk

GEM production

the beginning

Interconnection technologies available at MPT in 1996



Minimum line and space

Technologies name

200um

Screen printed circuits

120um

PCB

90um

Thick film technology

75um

MCM/L laminated

50um

MCM/C ceramic

25um

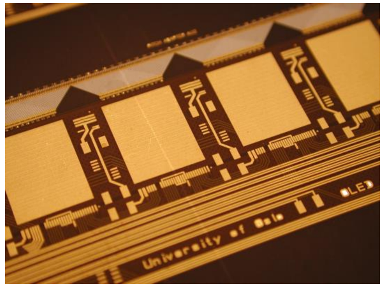
Thin film technology

20um

MCM/D deposited

MCM: Multi Chip Module
PCB: Printed Circuit Board

Interconnection technologies available at MPT in 1996



Minimum line and space	Technologies name
200um	Screen printed circuits
120um	PCB
90um	Thick film technology
75um	MCM/L laminated
50um	MCM/C ceramic
25um	Thin film technology
20um	MCM/D deposited

MCM: Multi Chip Module
PCB: Printed Circuit Board

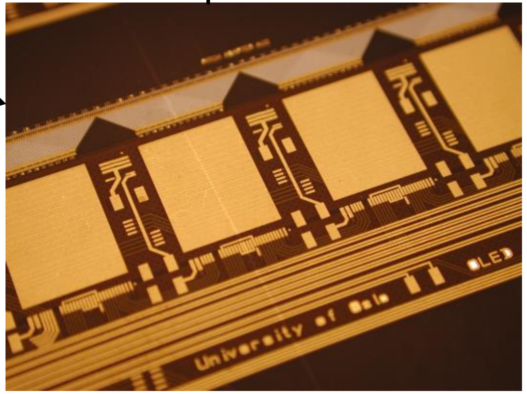
MCM / D

- Conductor material
  - AL 10um
  - Vacuum deposited
- Dielectric material:
  - Photo-imageable Liquid polyimide (PI)
  - 20um thick
  - deposited with a spinner
- Photolithography:
  - Minimum track 20um
  - Minimum via hole 25um
- Substrate :
  - TPG (Thermally annealed Pyrolytic Graphite)

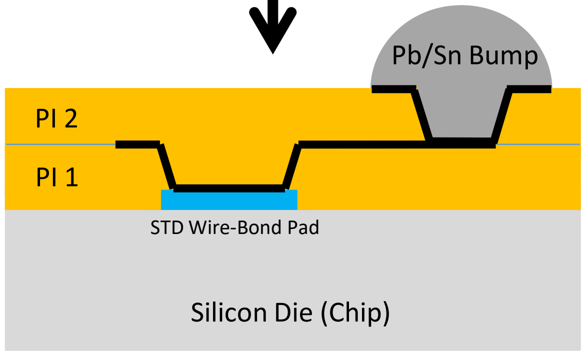
But the important detail is :

-PI stripper :Ethylene Diamine (EDA)

Atlas strip detectors R&D



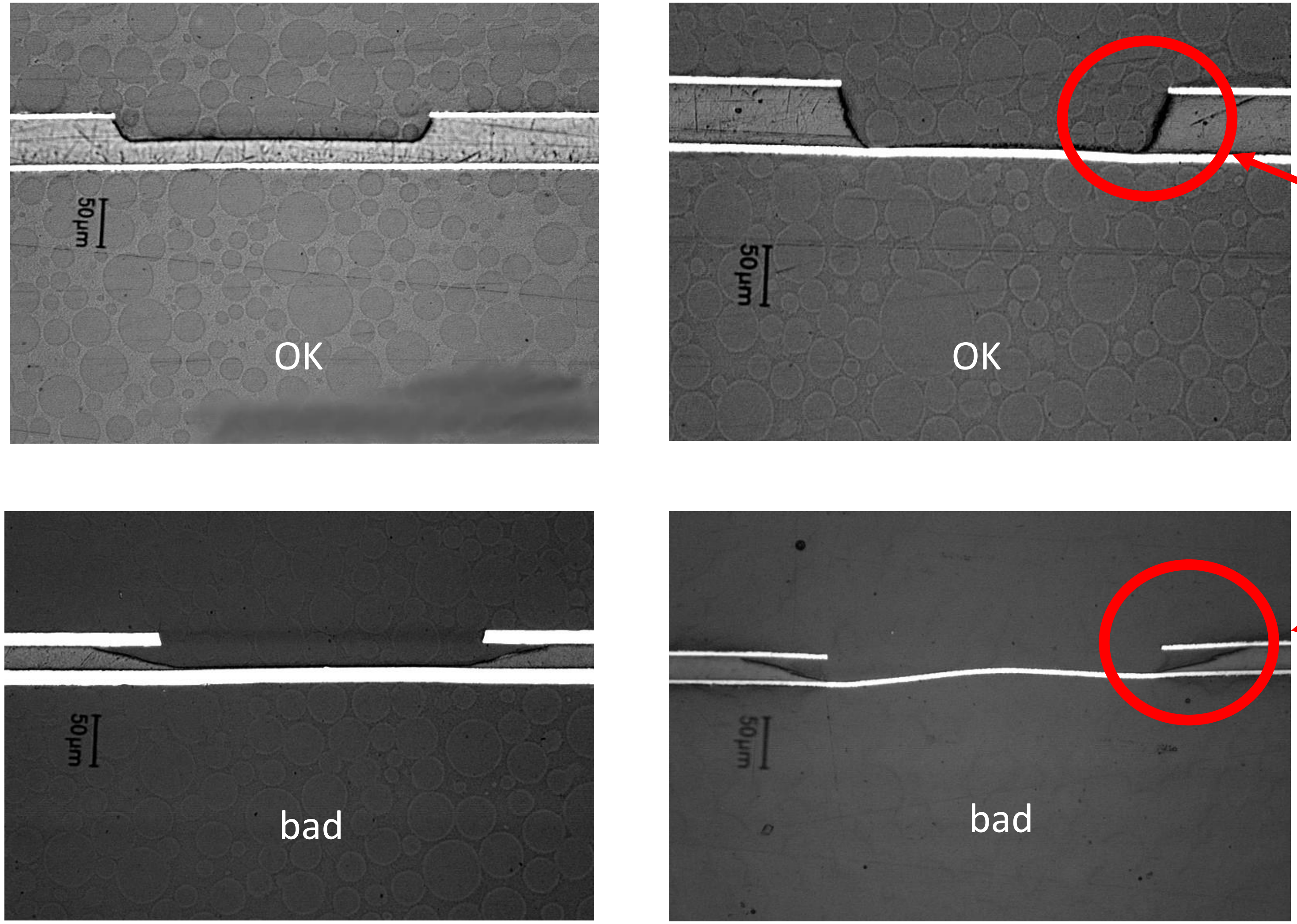
liquid PI typical application:
-Chip Scale Package (CSP)
-or Chip passivation



Fabio Sauli visit in 1996

- Fabio was originally looking for a electron preamplifier stage to improve MSGCs
- Request : foil with small holes of 100 to 200um
- Electrode on both sides
- And large size : 20cm x 10cm !

Survey on Polyimide etching with EDA



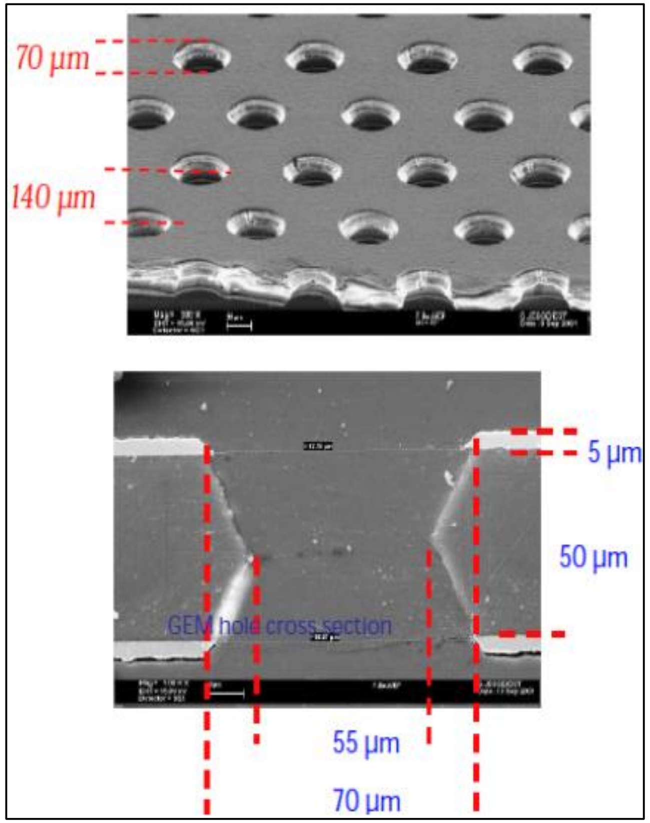
First type of polyimide:
Perfect anisotropic etching
No under etch
Perfect to make small holes

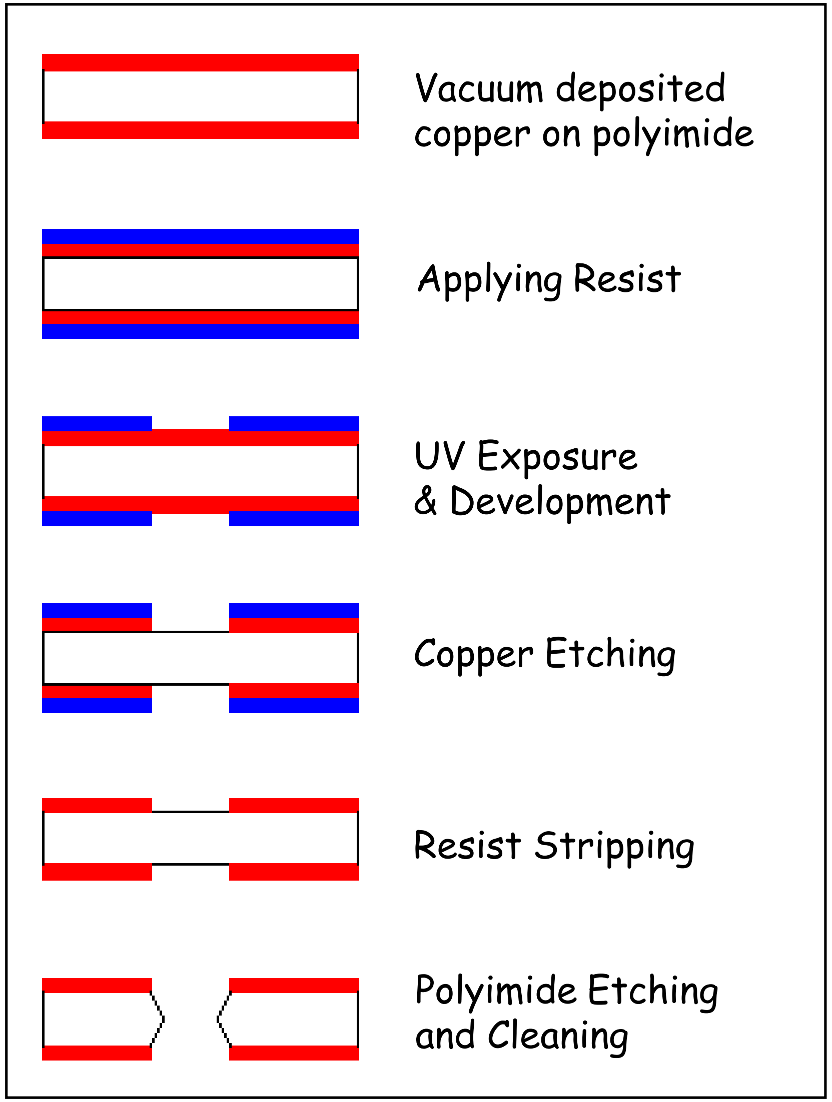
Second type of polyimide:
Fully isotropic etching
Not satisfactory

We were lucky to find immediately a good candidate since there is more than 50 different PI types on the market

GEM Manufacturing Process

Optimum pattern for physics
Obtained after many trials





Vacuum deposited copper on polyimide

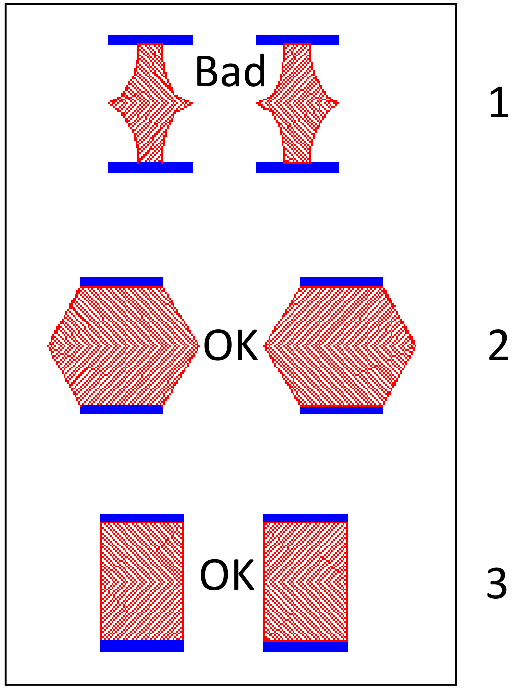
Applying Resist

UV Exposure
& Development

Copper Etching

Resist Stripping

Polyimide Etching and Cleaning



Manufacturing Process

Resist lamination

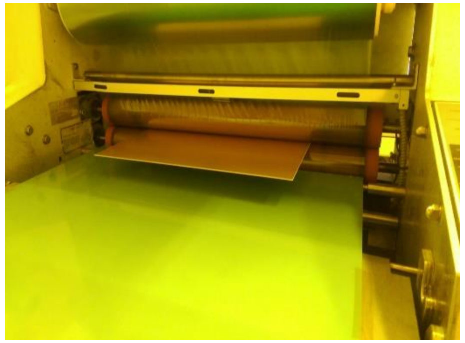
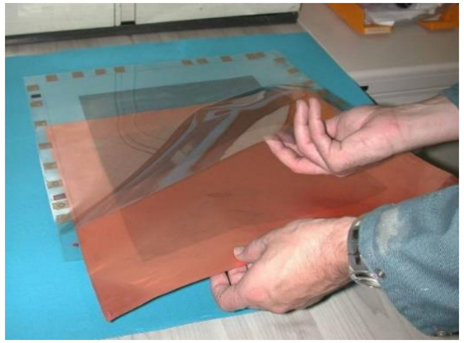


Image transfer

2 aligned films pocket

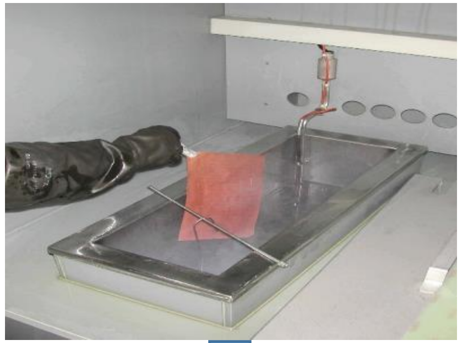


Copper Etching

Chemical spray

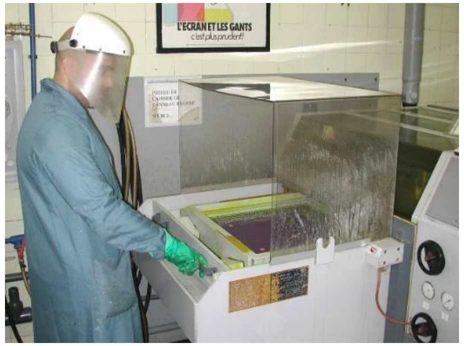
PI Etching

Dead bath



2nd lamination

2nd image Transfer

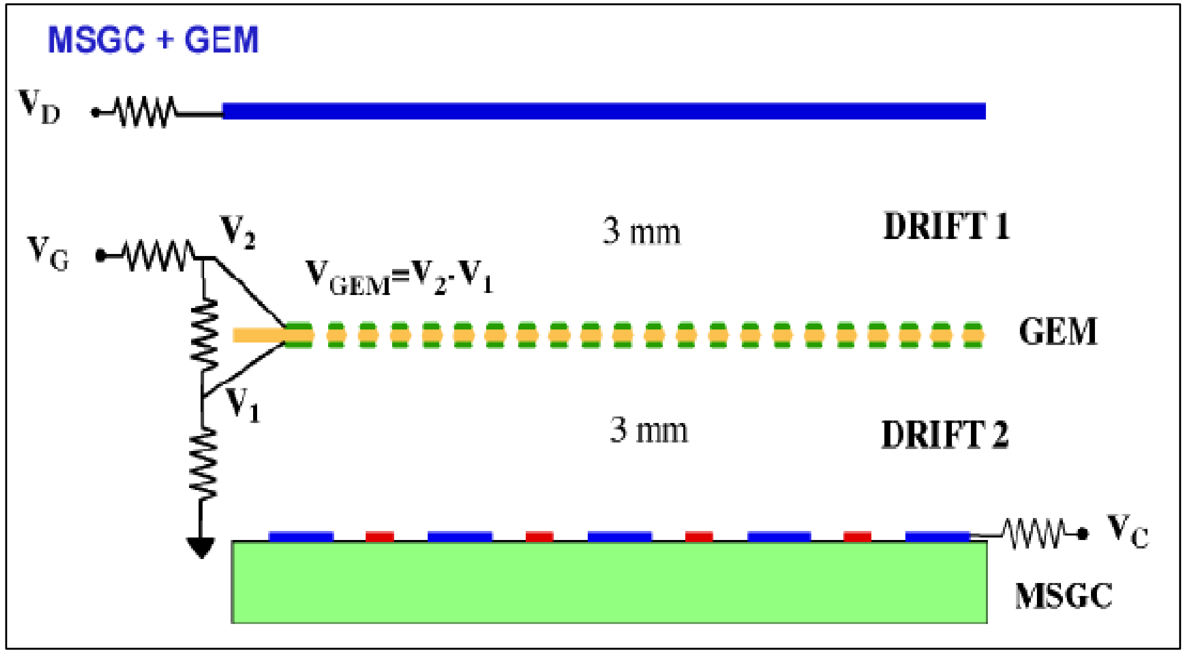


2nd copper etch

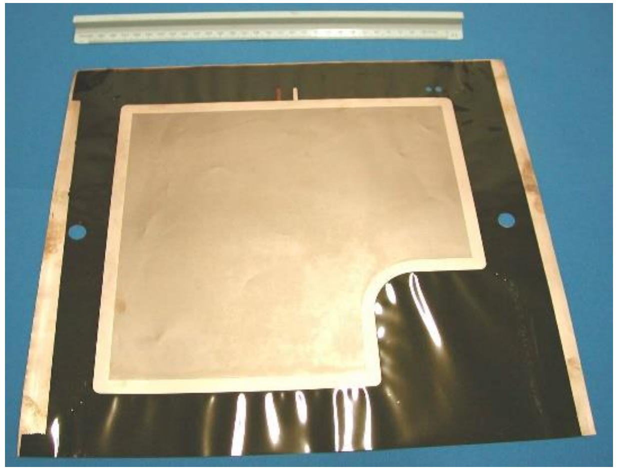
HV test

GEM first application

Reduce the spark risk on the MSGC by doing part of the amplification in the GEM



The GEM gas gain was only 10
Today the GEMs can reach easily a gain of many hundred

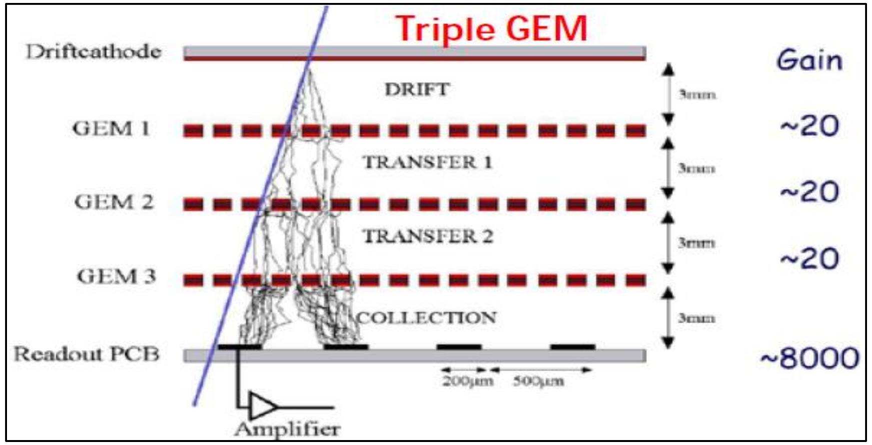


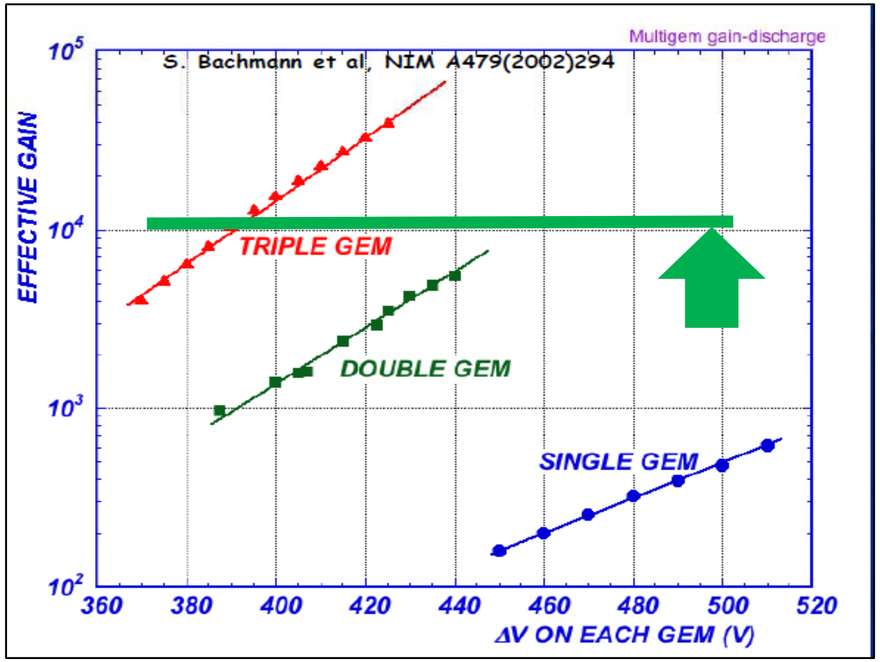
First real application:
Save the HERA-B Experiment
(300 GEMs)
200mm x 200mm

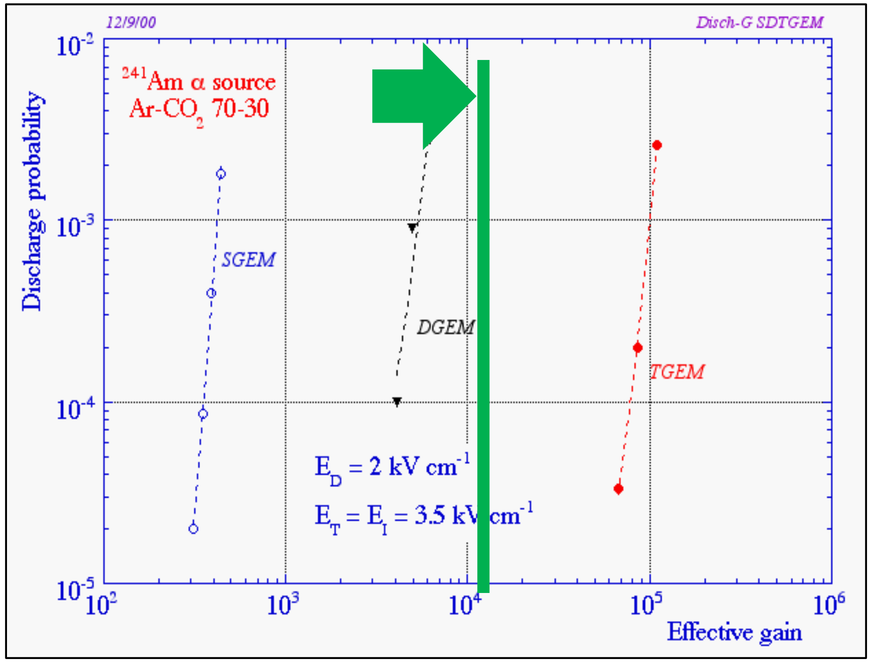
Triple GEM = detector

A cascade of multiple GEMs permit to reach high gains (> 10^4) before discharges with lower voltage for each GEM.

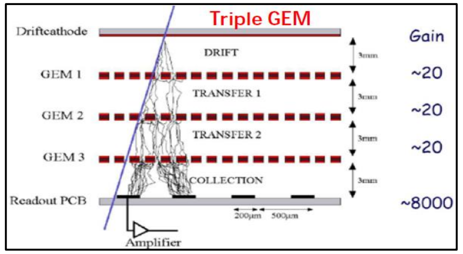
Gain is increased by about one order of magnitude at each addition of a GEM.

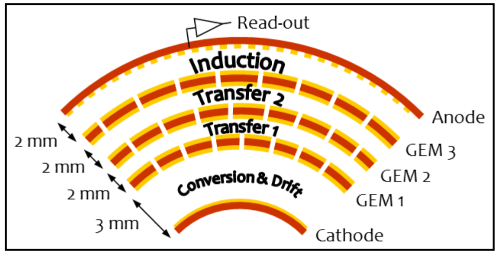


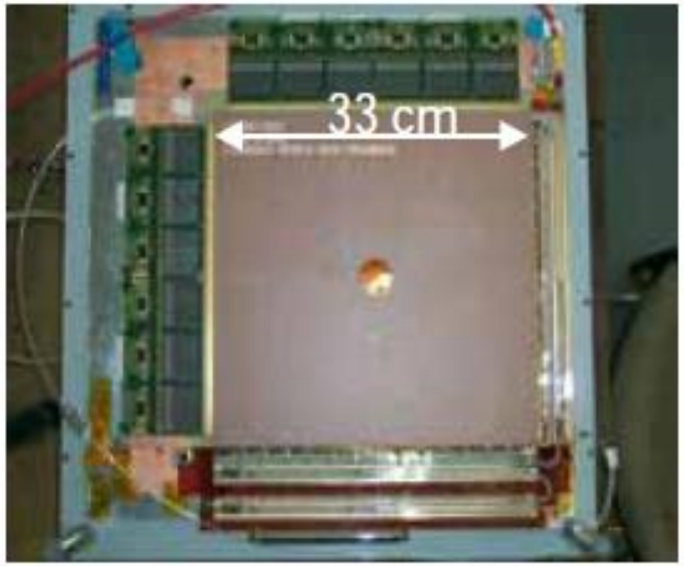




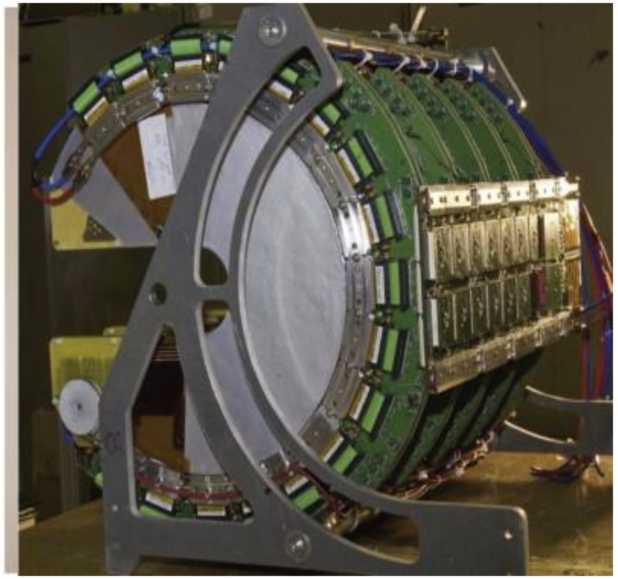
Triple GEM = detector



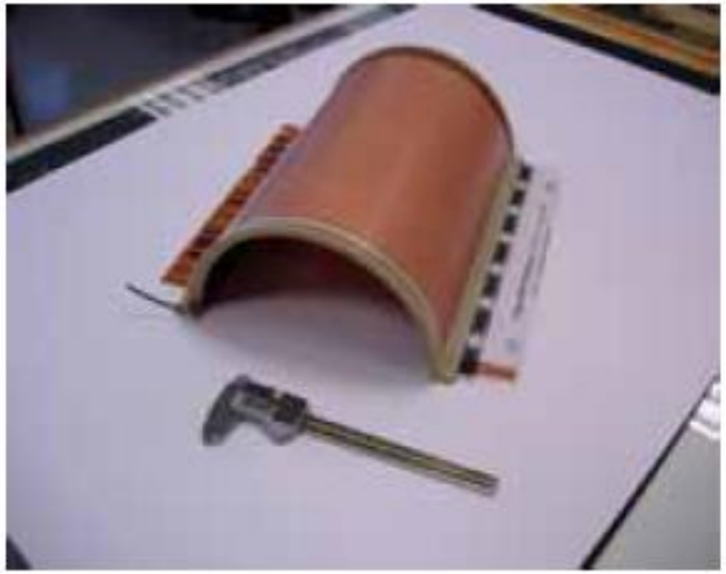




Compass settled all the parameters:
- -GEM Segmentation
- -HV distribution
- -X/Y Read out board
- -FE electronics



TOTEM
30cm diameter



Cylindrical R&D
40cm x 40cm

But the community started to ask for larger detectors.

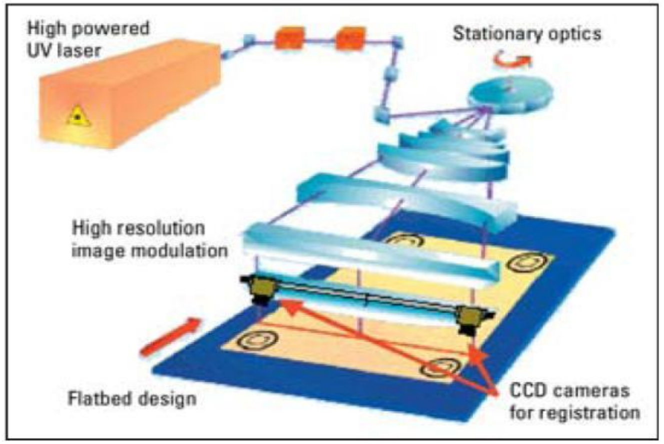
We tried to increase the mask size using the same technique.
We faced unsolvable problems with mask alignment.
The cost of glass mask is prohibitive
15 000 CHF for 1m x 0.6m.

We manage to patch GEMs but this was a bit too complex.

We then tried to use the best automatic alignment machine available on the market.

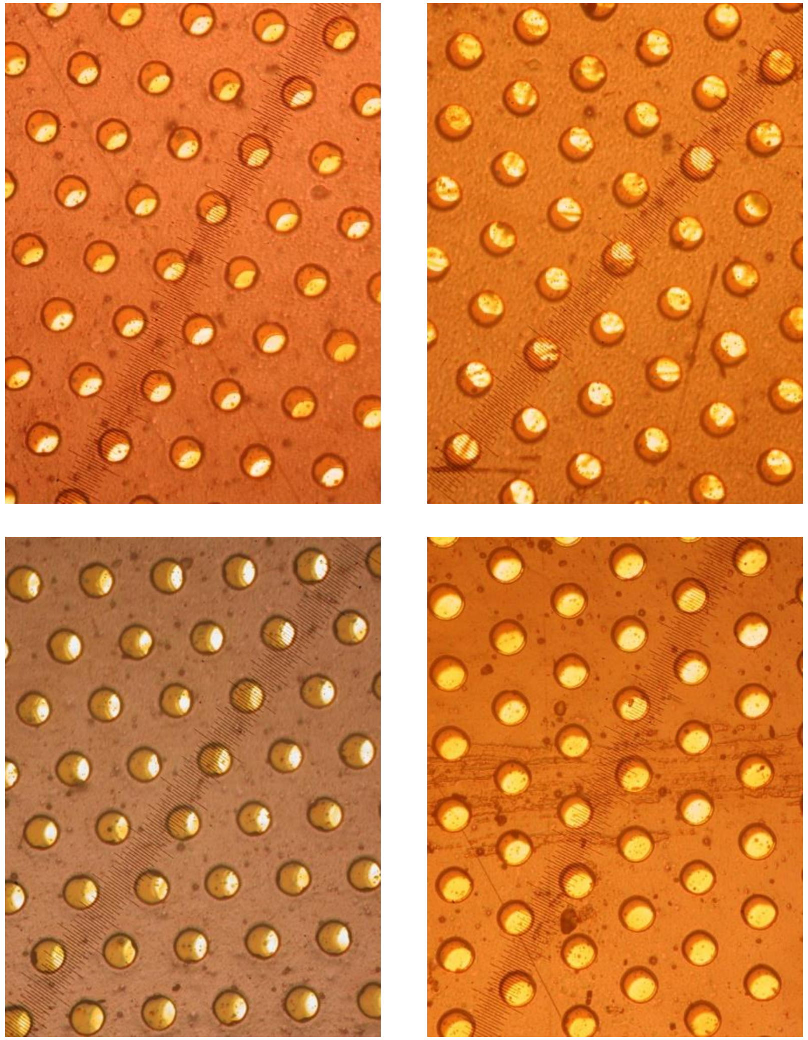
LDI laser direct imaging

Figure 2 e 3 – The Paragon-8000 Laser Direct Imaging system (above) and 25 µm features exposed using this system (below)



Direct laser exposure of resist following a GERBER file.
Scanning process

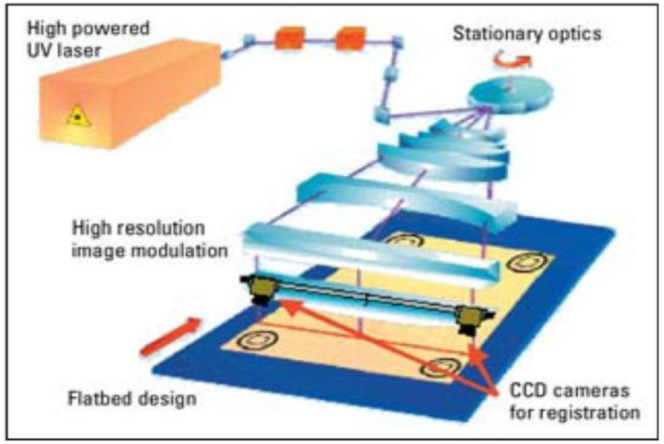
Top to bottom alignment :
Announced +/-15um
Real +/- 40 um



Corners of a 800mm x 400mm GEM

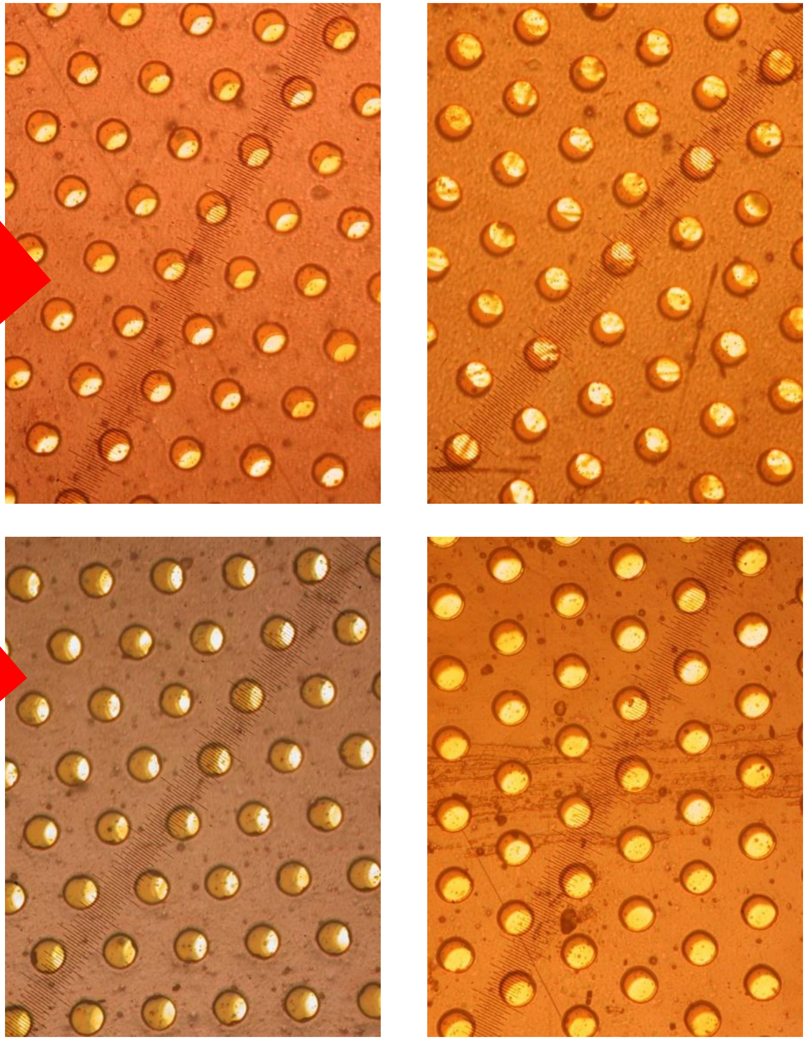
LDI laser direct imaging

Figure 2 e 3 – The Paragon-8000 Laser Direct Imaging system (above) and 25 µm features exposed using this system (below)



Direct laser exposure of resist following a GERBER file.
Scanning process

Top V :



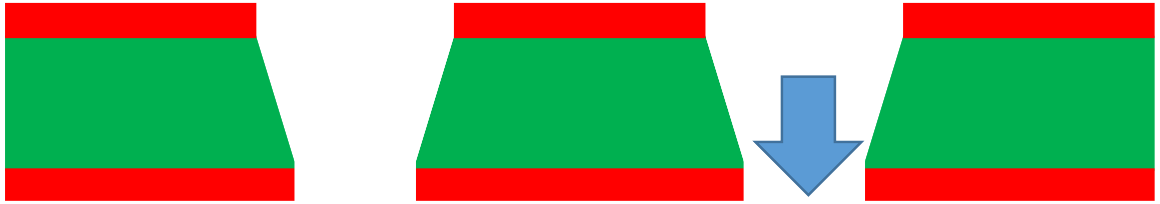
Corners of a 800mm x 400mm GEM

Why not using only one mask to skip alignment?

1/ etch holes in the top copper with one mask

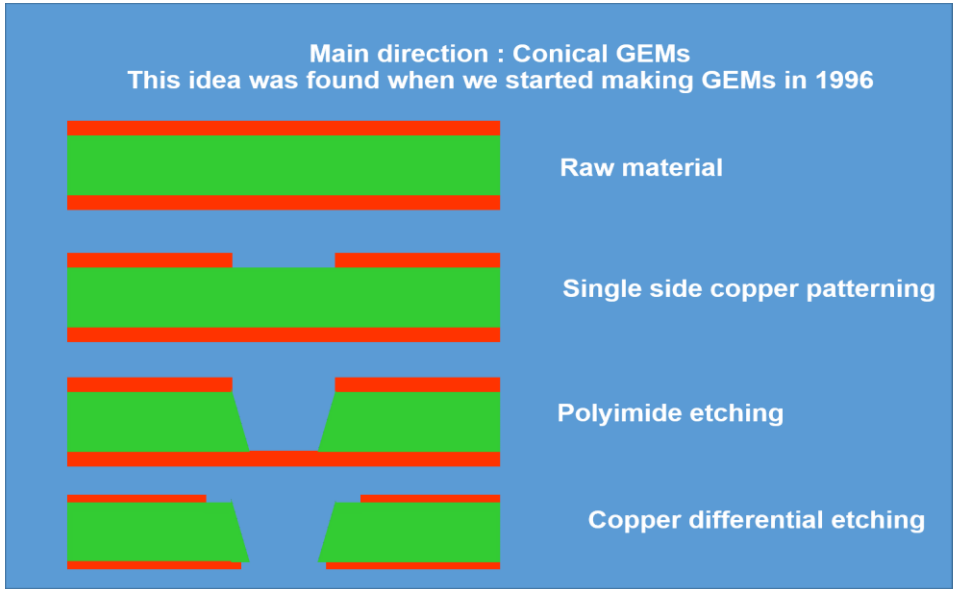
2/etch the Polyimide through the copper holes

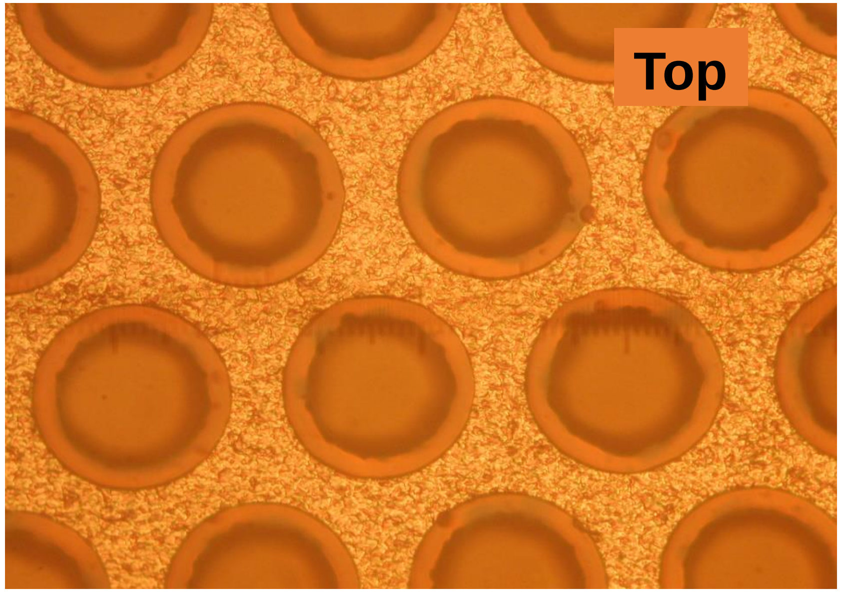
3/ etch the bottom copper through the PI holes

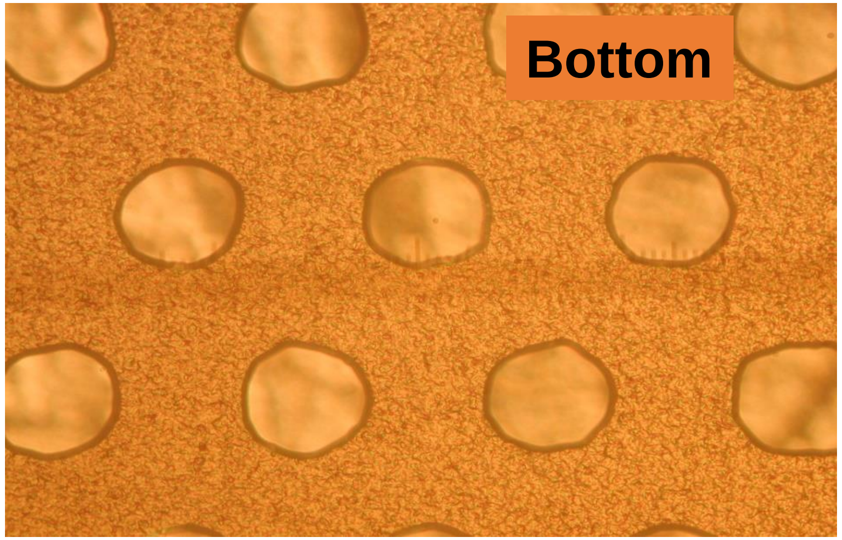


Problem → how to etch the bottom copper without etching the TOP copper ?

Differential etching

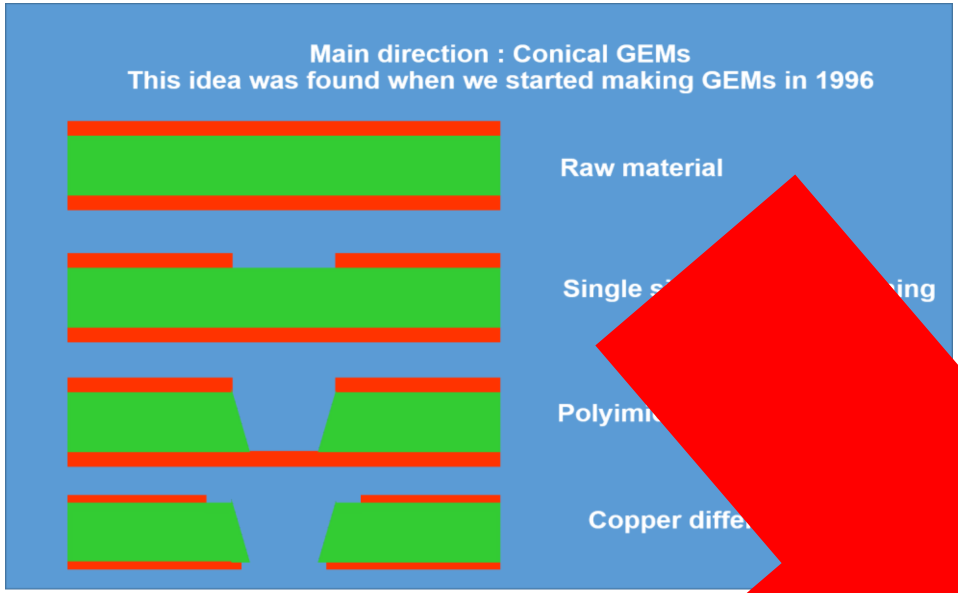




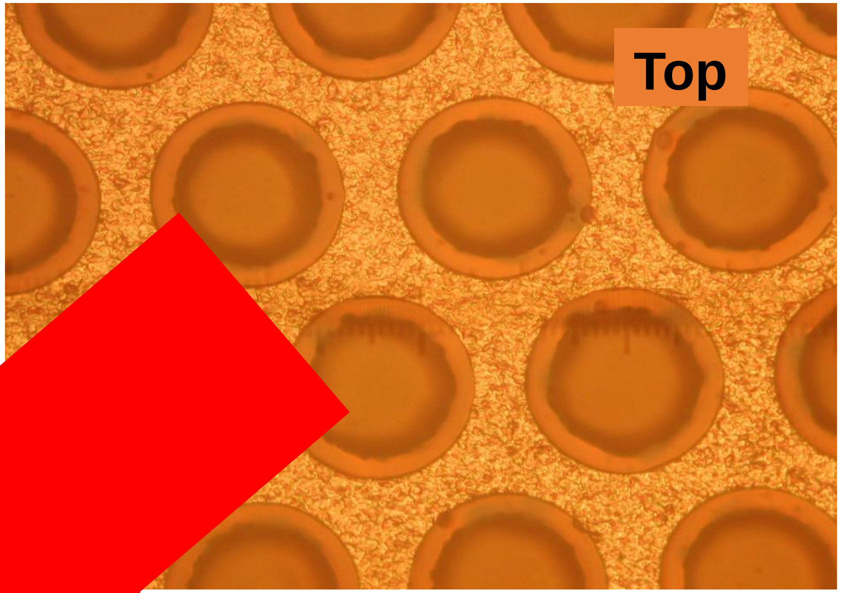


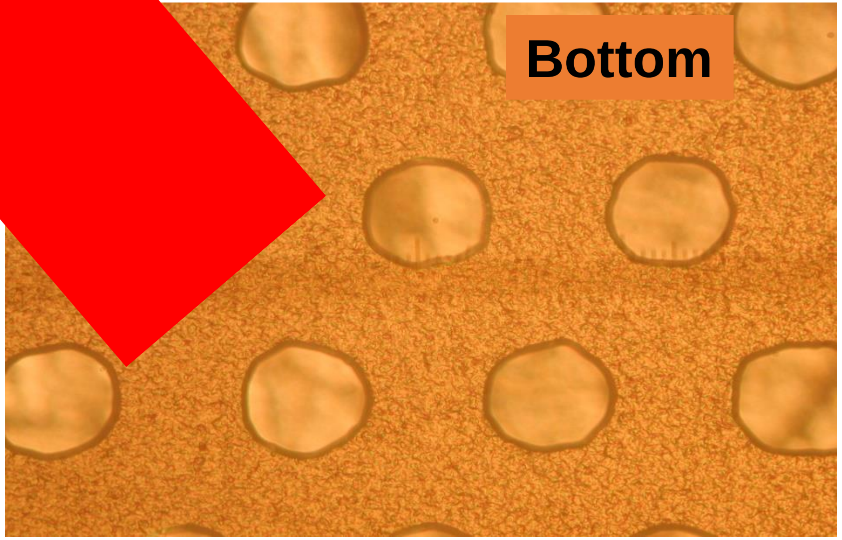
Working but:
- -Large rims
- -Bad yield
- -Hole shape too conical
- -Charging up
- -Lower gain

Differential etching



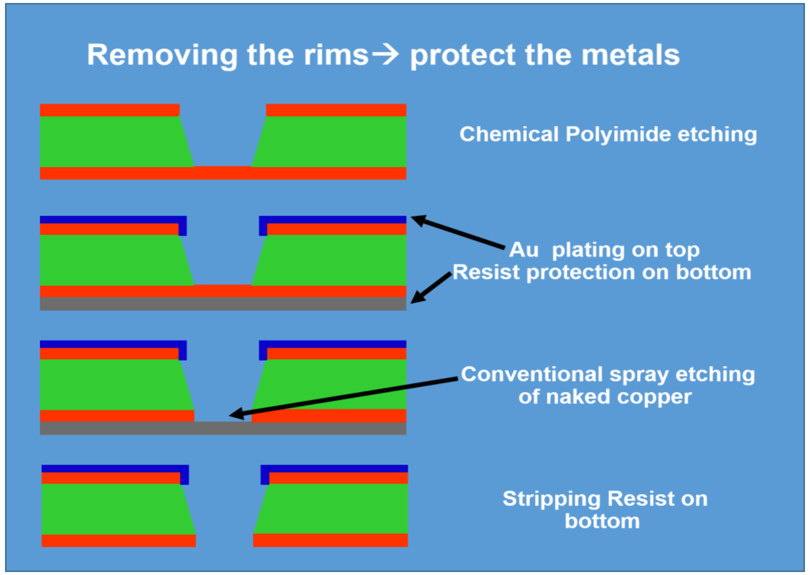
Main direction : Conical GEMs
This idea was found when we started making GEMs in 1996





Working but:
- -Large rims
- -Bad yield
- -Hole shape too conical
- -Charging up
- -Lower gain

Top copper plating protection



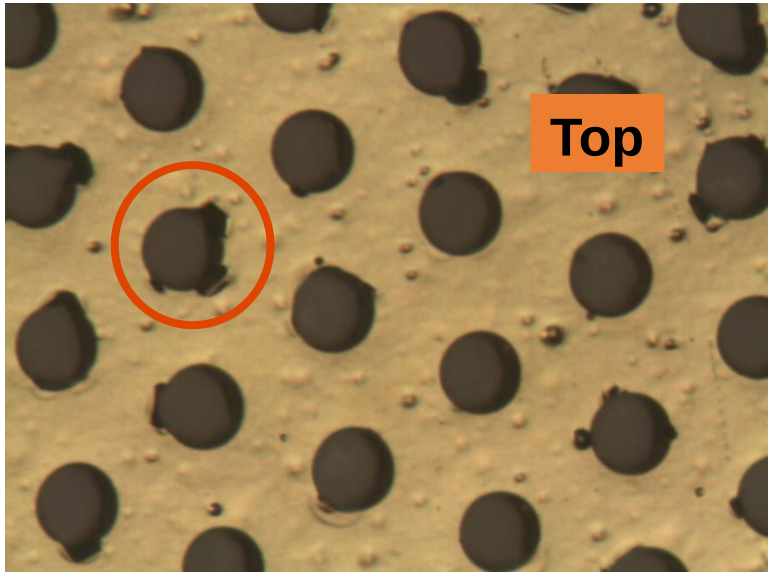
Removing the rims→ protect the metals

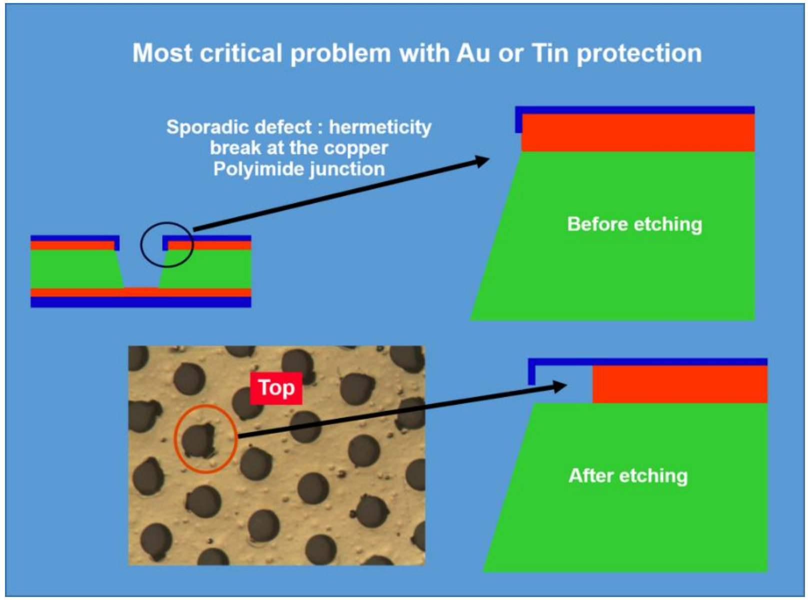
Chemical Polyimide etching

Au plating on top
Resist protection on bottom

Conventional spray etching
of naked copper

Stripping Resist on
bottom



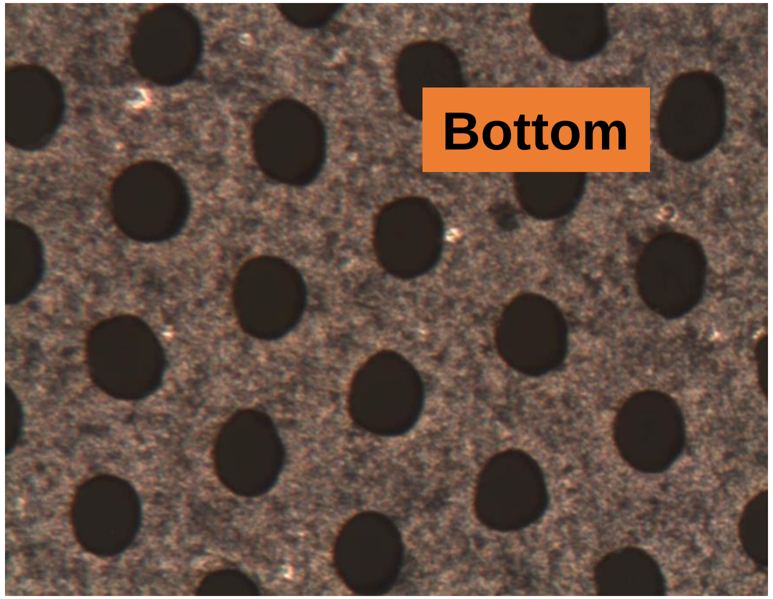


Most critical problem with Au or Tin protection

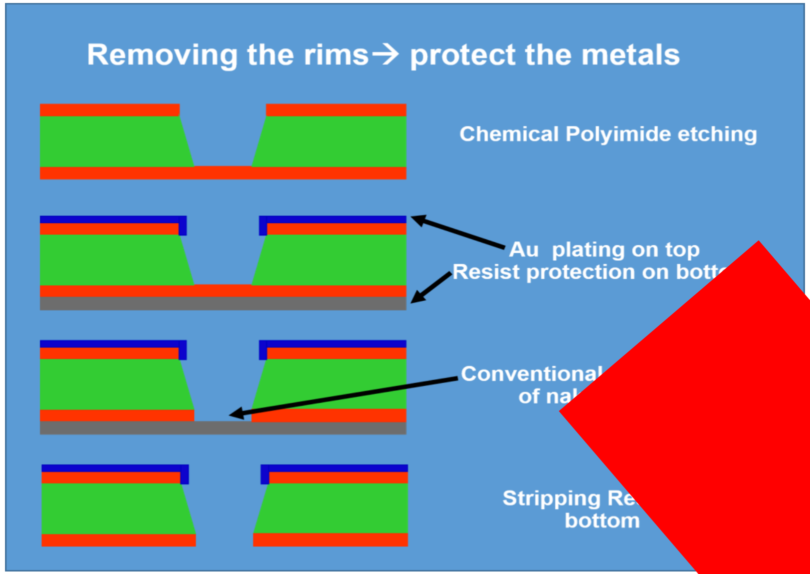
Sporadic defect : hermeticity
break at the copper
Polyimide junction

Before etching

After etching



Top copper plating protection



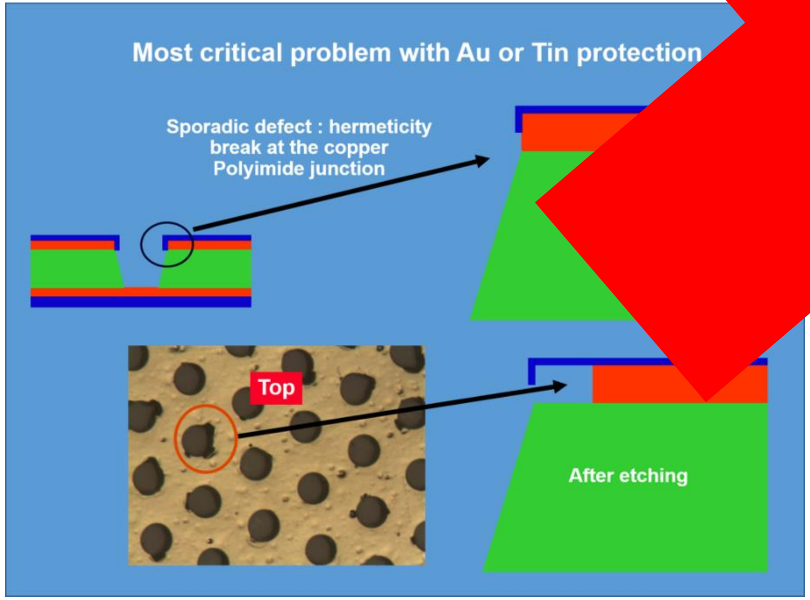
Removing the rims→ protect the metals

Chemical Polyimide etching

Au plating on top
Resist protection on bott

Conventional
of nal

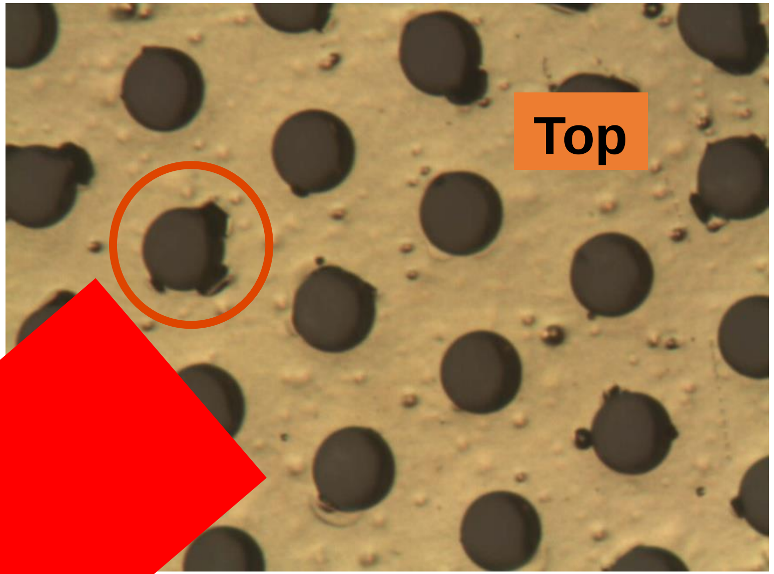
Stripping Re
bottom

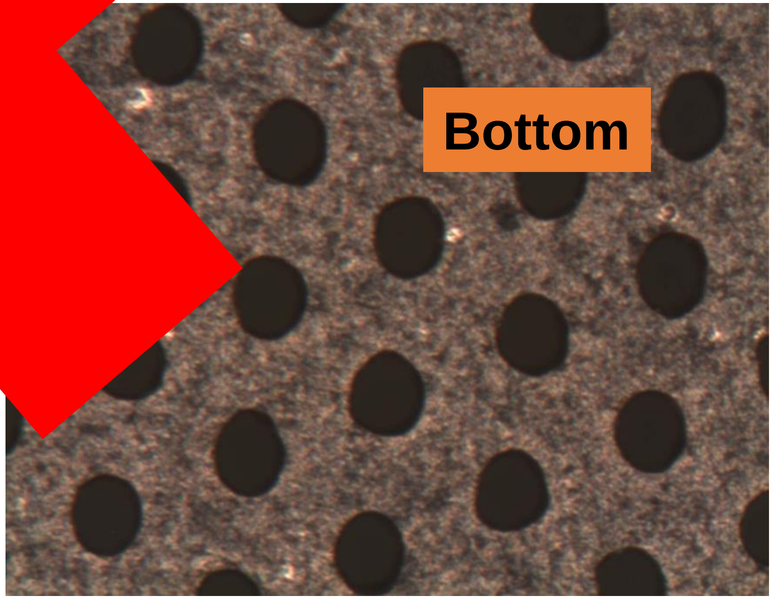


Most critical problem with Au or Tin protection

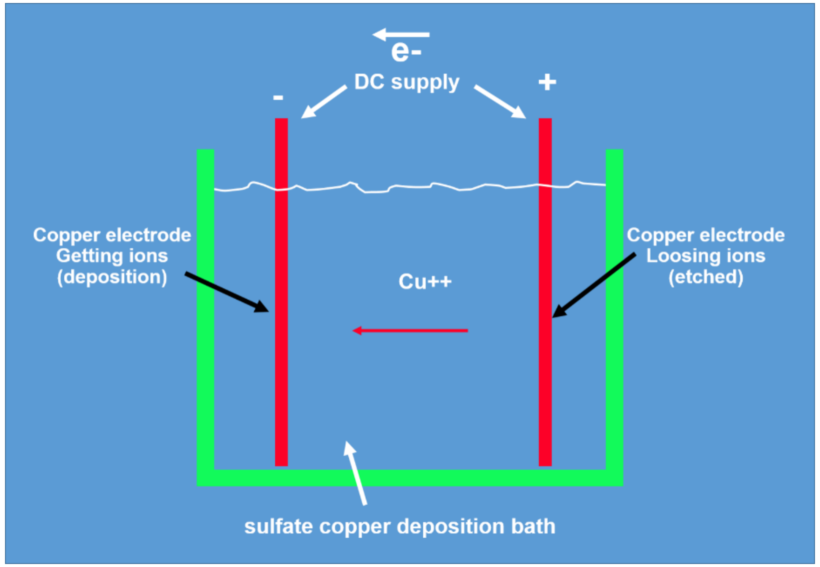
Sporadic defect : hermeticity
break at the copper
Polyimide junction

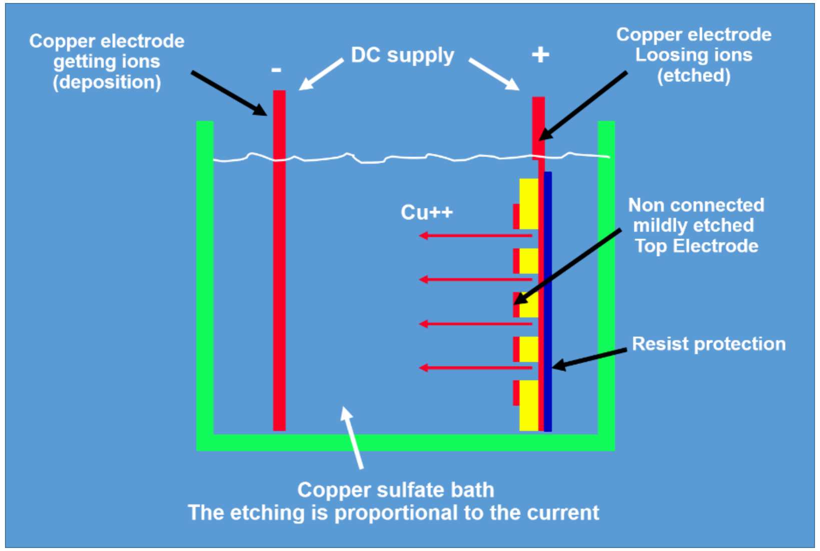
After etching

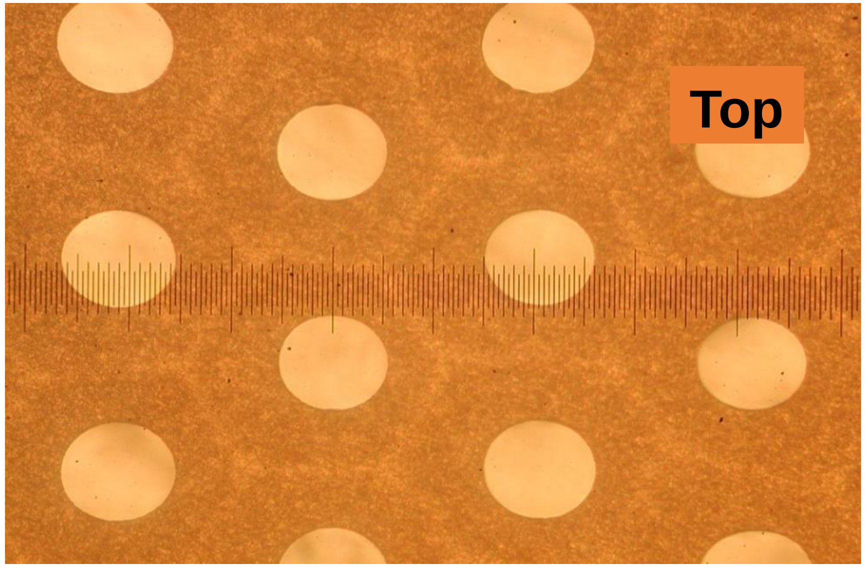


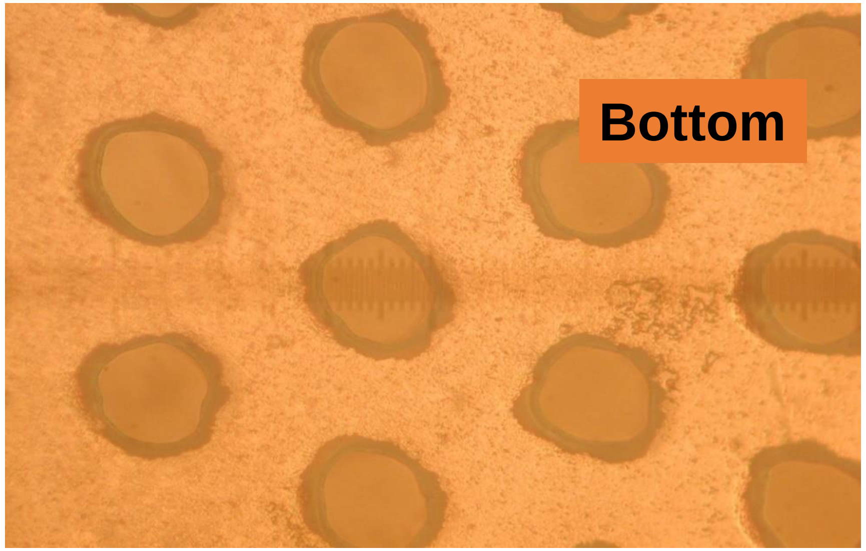


Invert a Copper plating bath

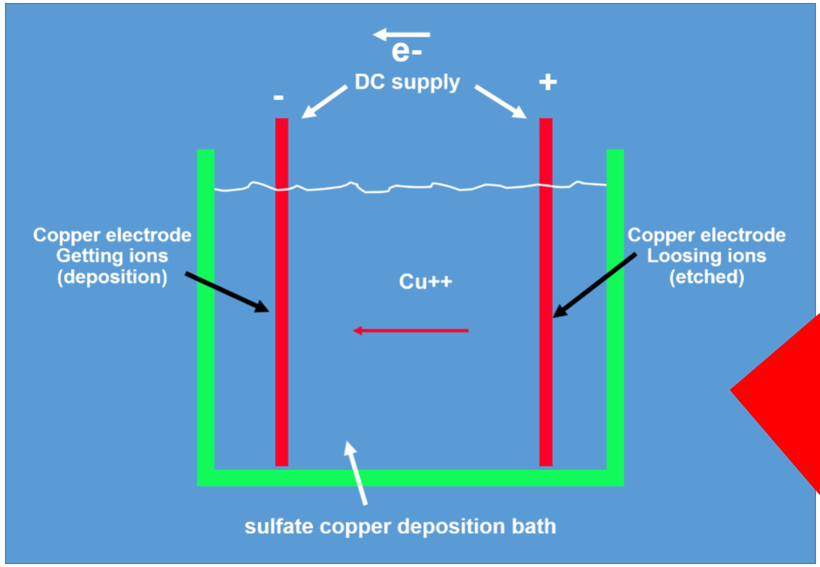


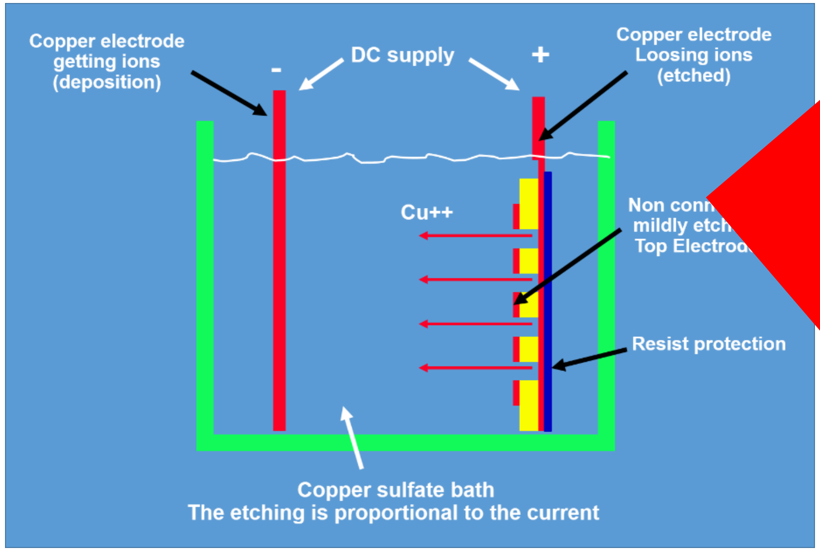


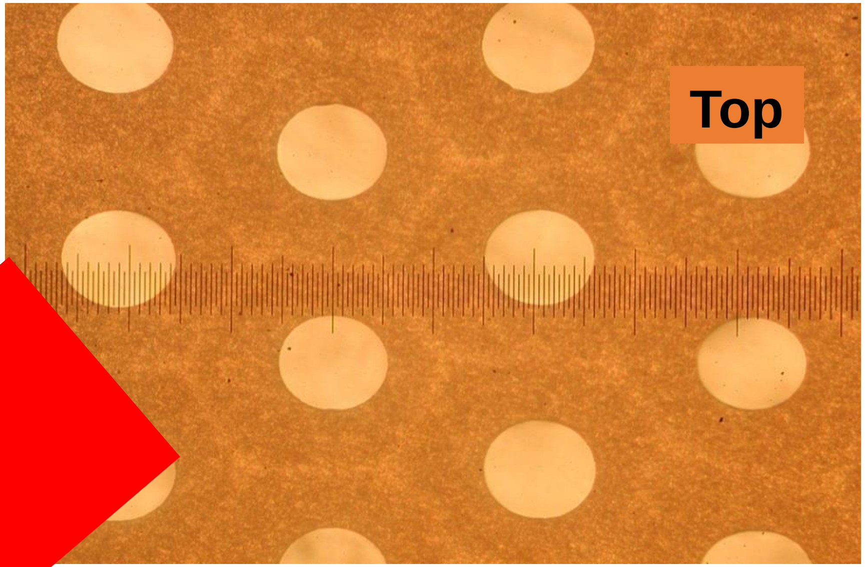


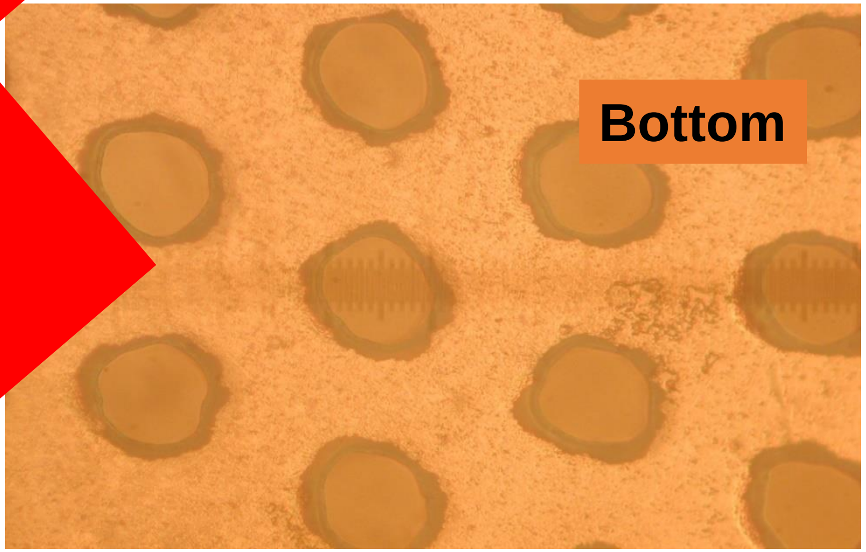


Invert a Copper plating bath

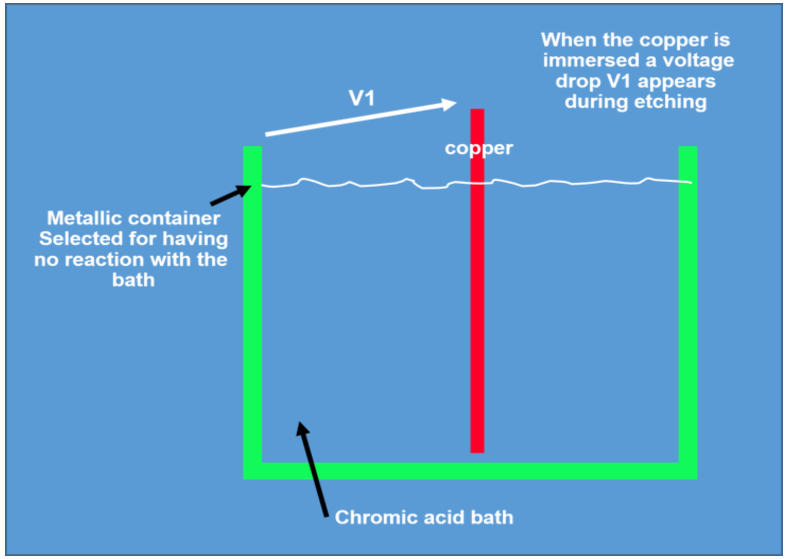




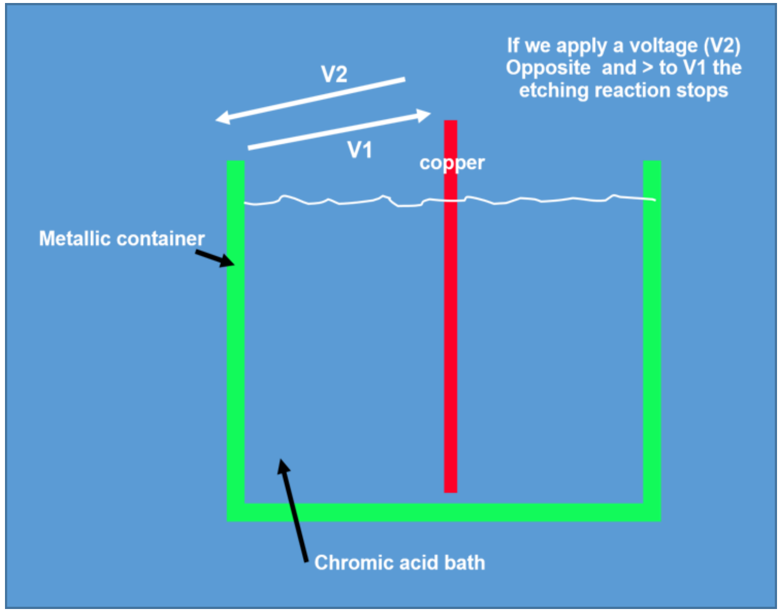


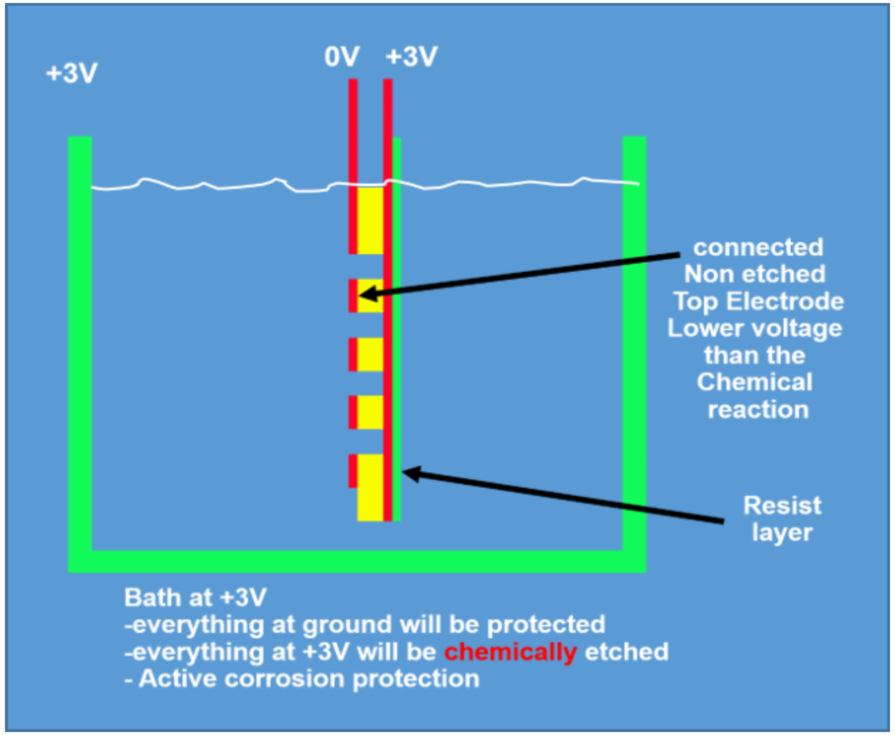


Electro protection & chemical etching


When the copper is immersed a voltage drop V1 appears during etching

Metallic container Selected for having no reaction with the bath

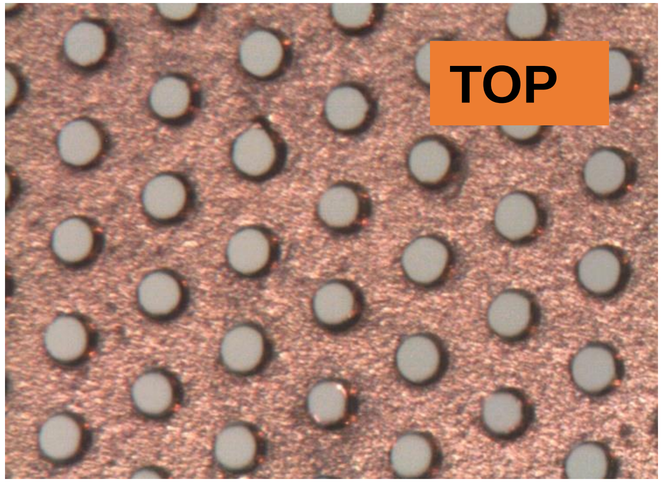

If we apply a voltage (V2) Opposite and > to V1 the etching reaction stops

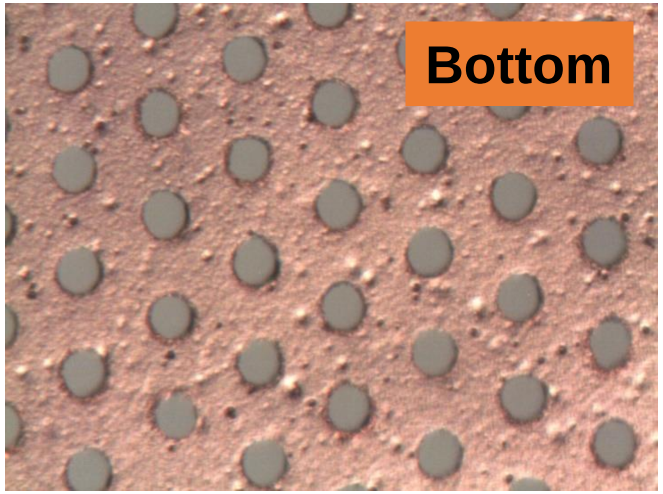


connected Non etched Top Electrode Lower voltage than the Chemical reaction

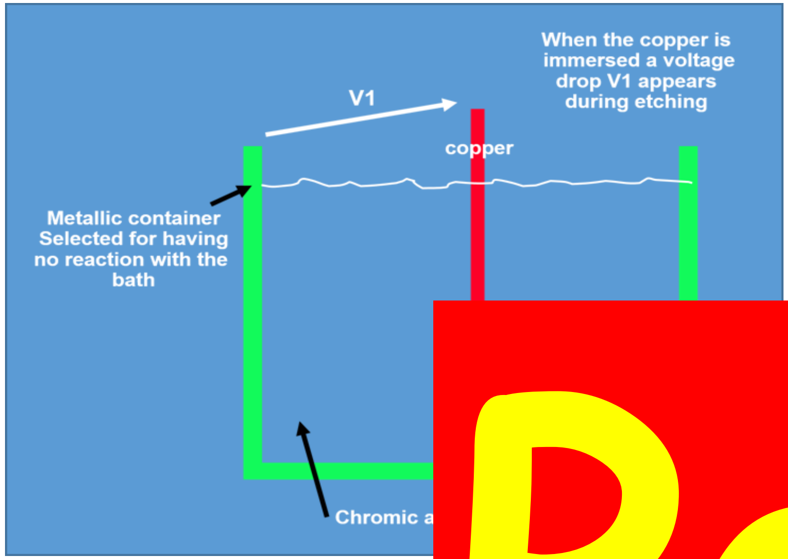
Resist layer

Bath at +3V
-everything at ground will be protected
-everything at +3V will be chemically etched
- Active corrosion protection



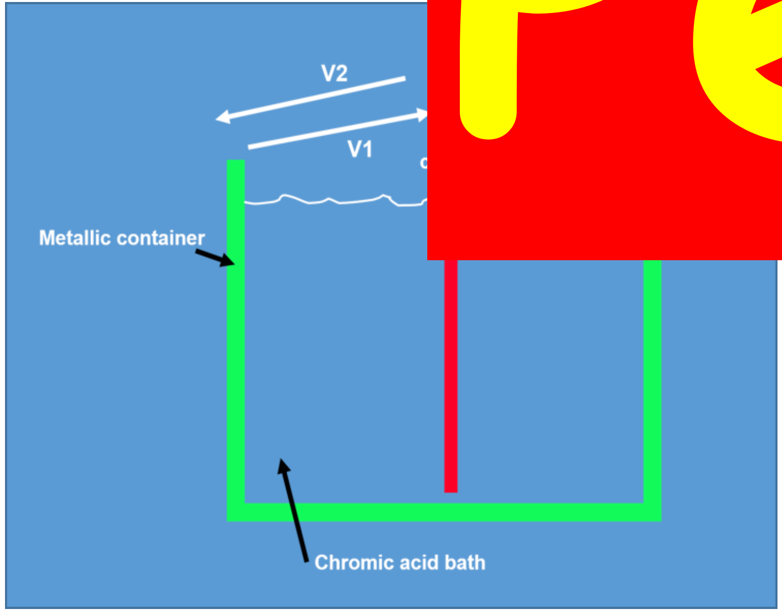


Electro protection & chemical etching

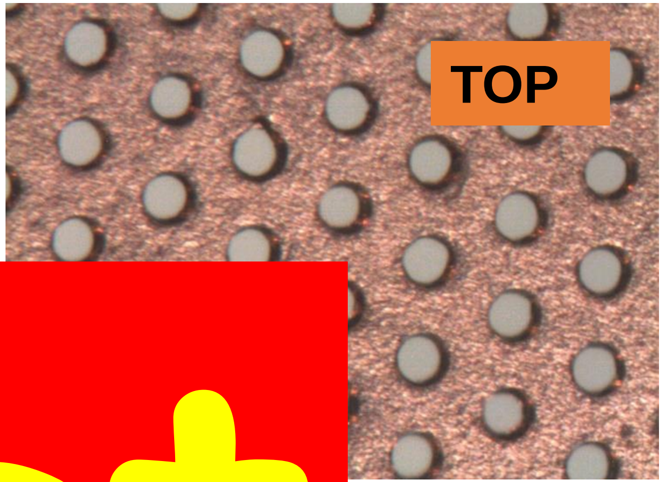


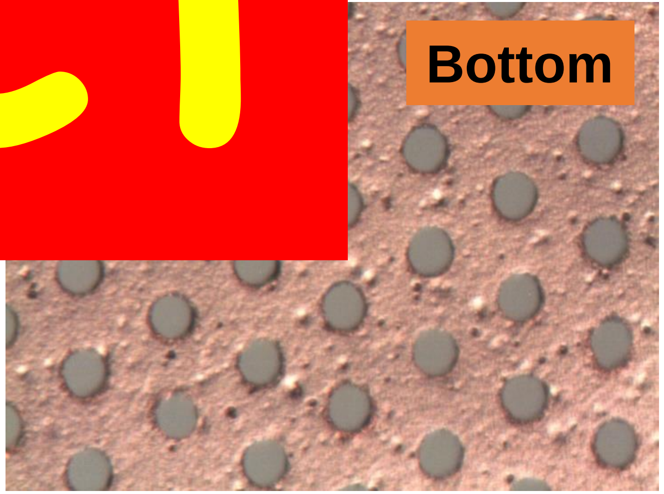
When the copper is immersed a voltage drop V1 appears during etching

Perfect



-everything at +3V will be chemically etched
- Active corrosion protection

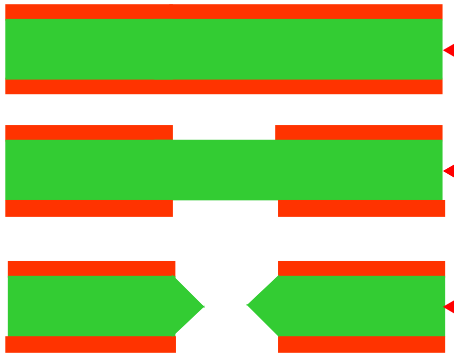




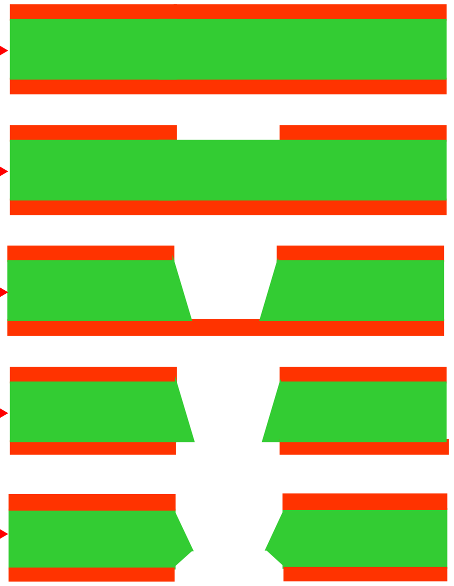
Double Mask Vs single mask

- Base material : Polyimide 50um + 5um on both sides

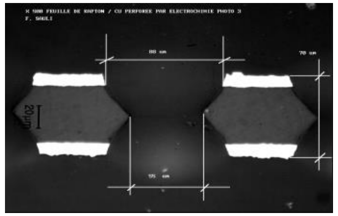
- Double mask



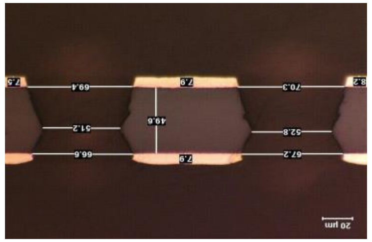
- Single mask



- Same base material
- Hole patterning in Cu
- Polyimide etch
- Bottom electro etch
- Second Polyimide Etch

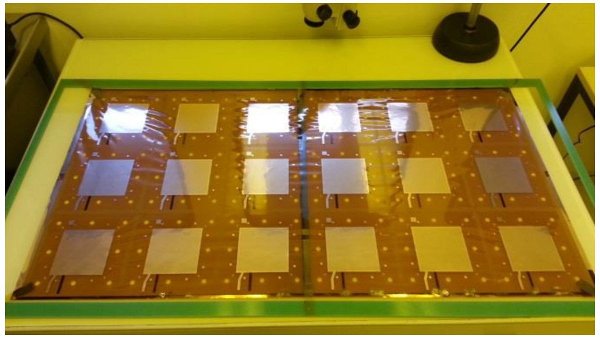


- Limited to 40cm x 40cm due to
  - Mask precision and alignment



- Limited to 2m x 60cm due to
  - Base material
  - Equipment

Single mask introduced cost reductions: 10cm x 10cm GEM example

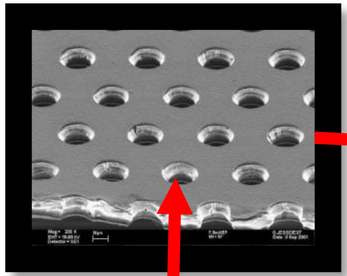


The 10cm x 10cm double mask GEM cost is 300 CHF/piece

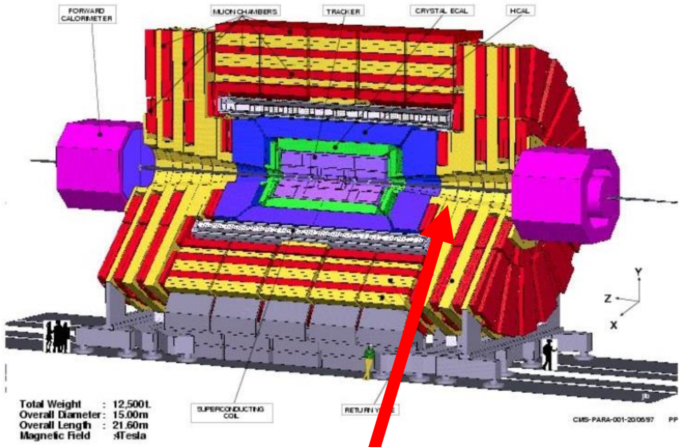
For 100 pieces with Single mask the cost dropped to 100 CHF/piece

For 10 000 pieces , less than 50 CHF

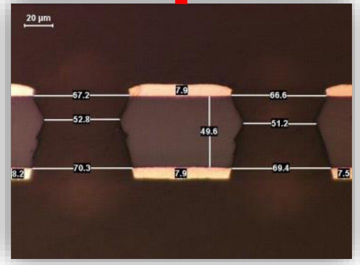
CMS GE1/1 application


Microscopic view

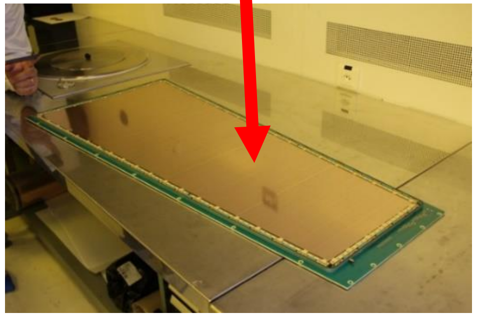

Single GEM



CMS experiment



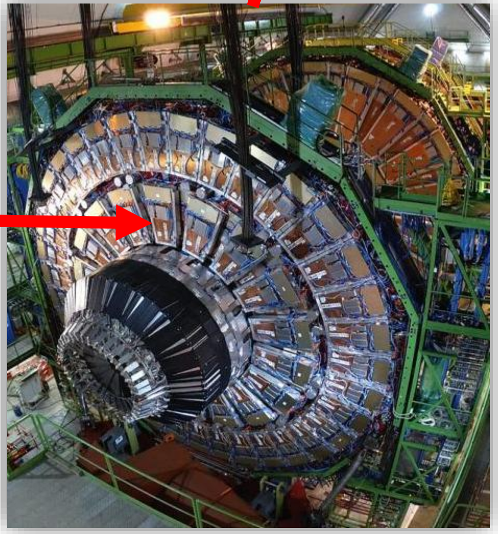
Cross section


Triple GEM stack
GE1/1 Muon detector

GE1/1 → 400 GEM (1.3m x 0.5m) made at CERN
GE2/1→ 1000 GEM (1.3m x 0.5m) CERN/Korea

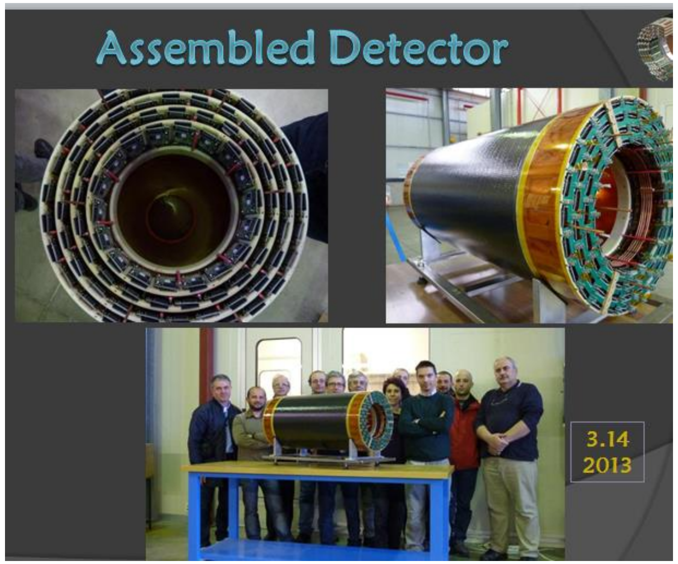
GEM producers capabilities:
-CERN MPT : 500m2/year
-Mecaro Korea : 250m2/year

Mecaro will finish half of GE2/1 end 2023
MPT will finish the other half mid 2023


CMS nose

Other detectors using single mask technique

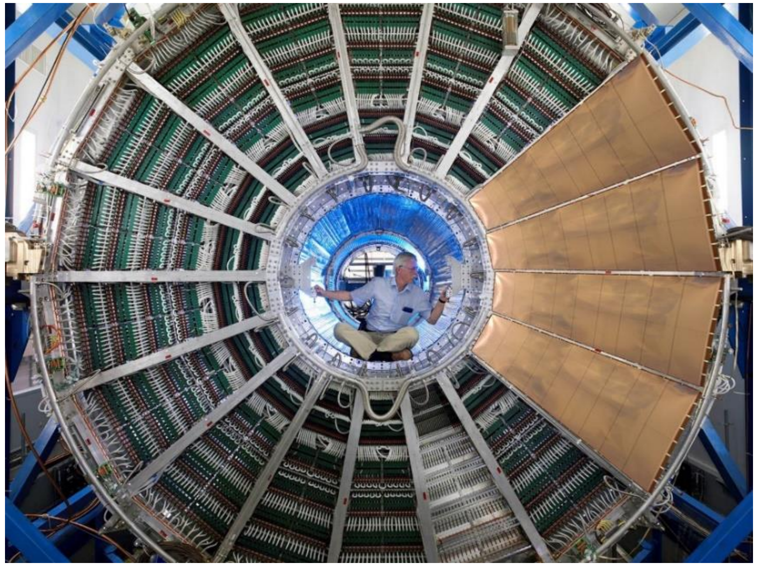
Future CMS ME0



Assembled Detector

3.14
2013

KLOE – Cylindrical Detector



ALICE TPC – 700 GEM

And many many more

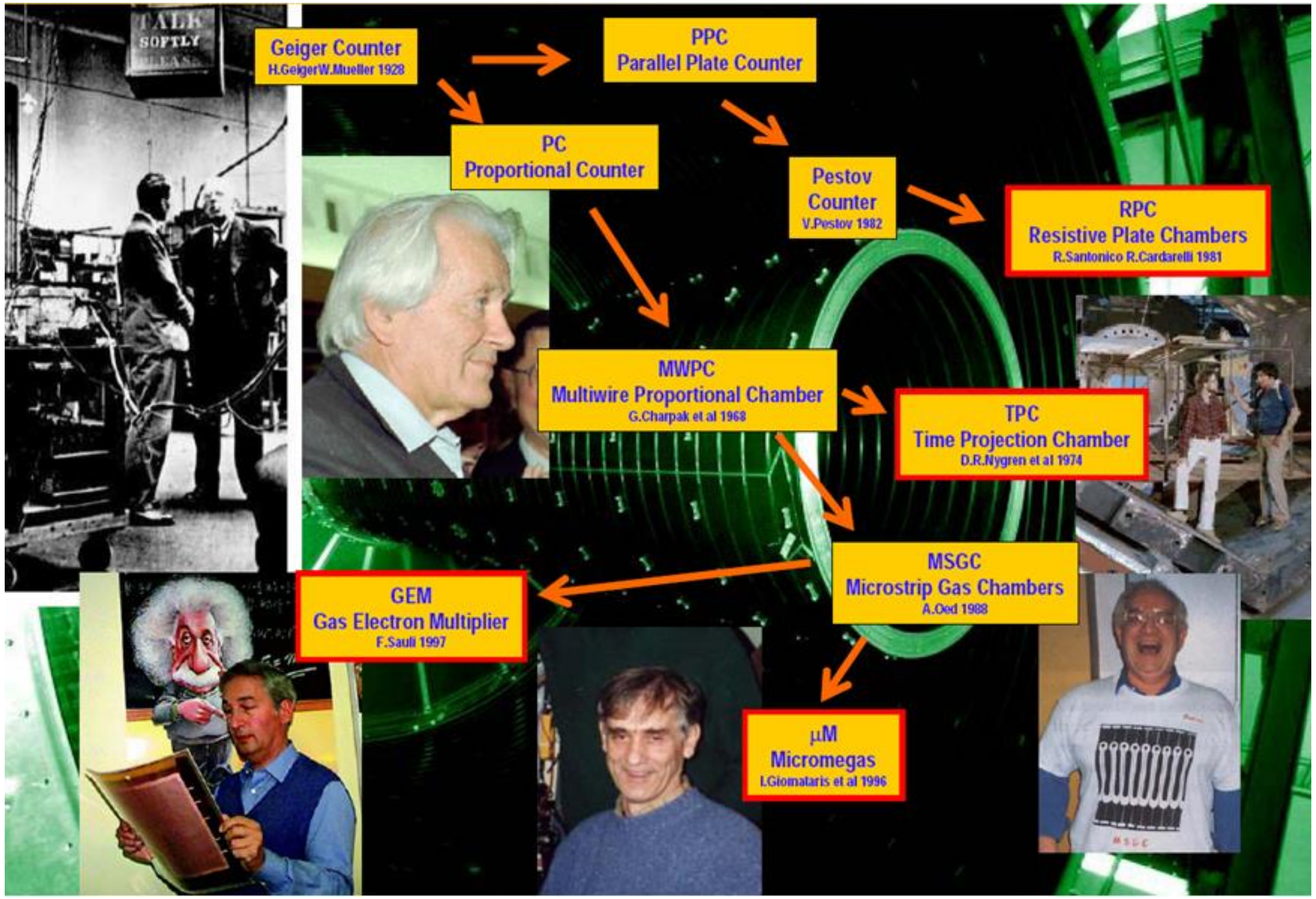
-BM@N in Dubna
-SBS tracker Jefferson lab
-CBM at Fair
-BESIII China

-SOLID
-BONUS 12
-P-RAD
-S-Phenix TPC

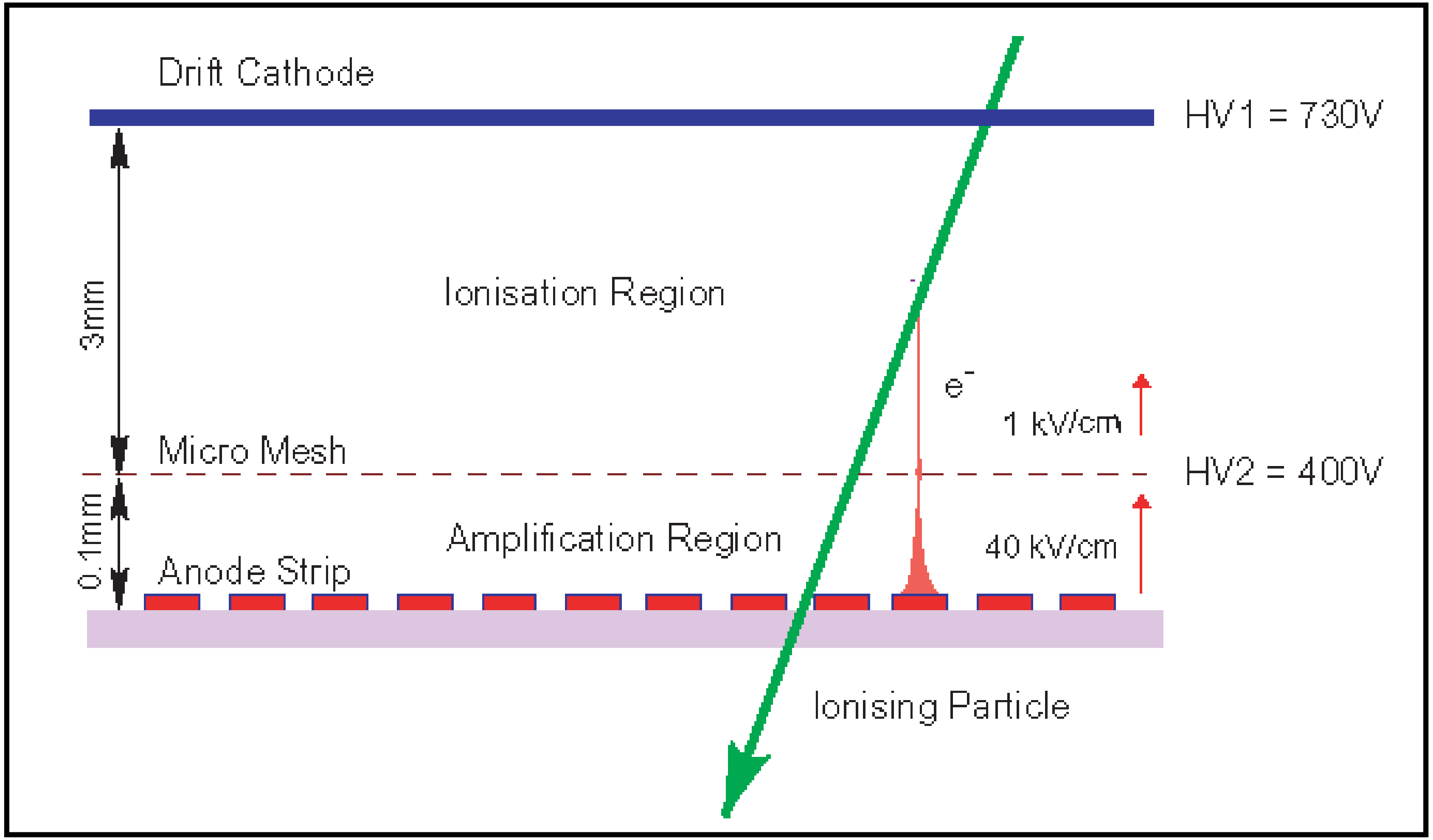
-COMPASS upgrade
-GEM for nuclear physics TPCs
-ESS for neutron detectors
-and lot of small GEMs for academic purpose

Micromegas

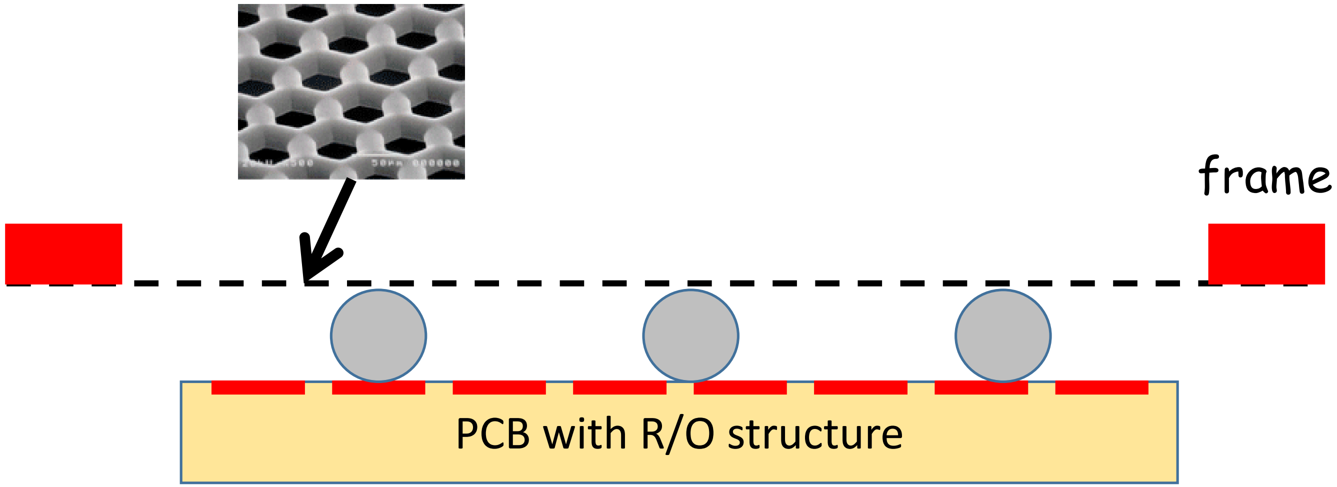
George Charpak and Ioannis Giomataris



Principle

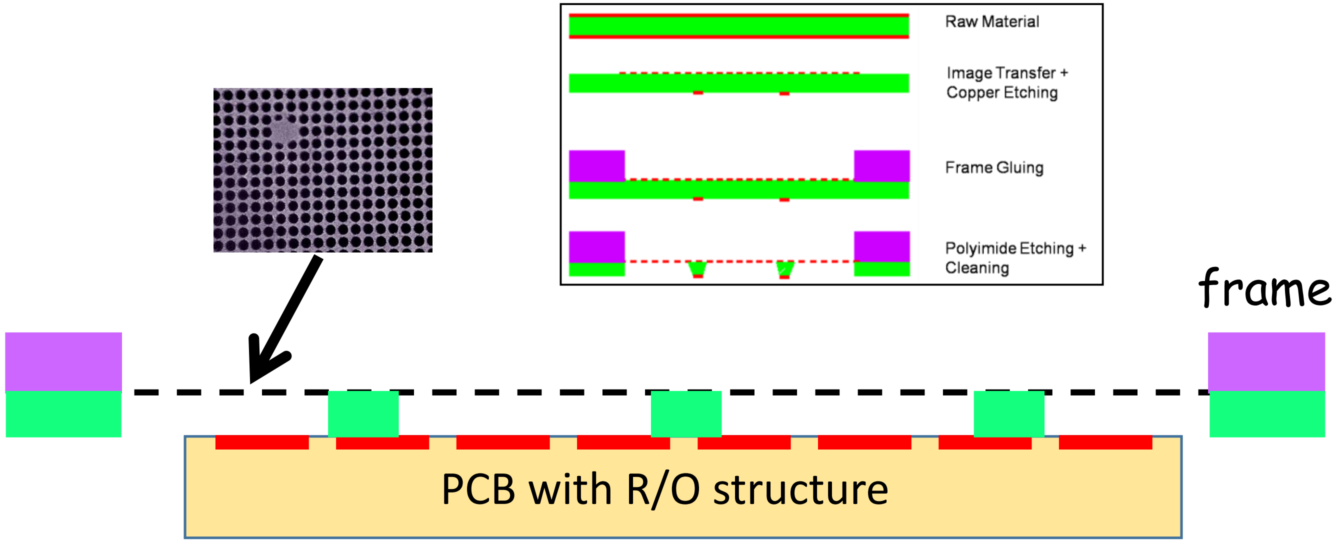

Drift Cathode
HV1 = 730V
3mm
Ionisation Region
e⁻
1 kV/cm
Micro Mesh
HV2 = 400V
0.1mm
Amplification Region
40 kV/cm
Anode Strip
Ionising Particle

Micromegas during early days



- -Electro formed mesh stretch on frame → ultra fragile
- -Amplification gap defined with fishing wires (really long & delicate job)
- -Good detector but a pain to produce
- -Low yield → small size
- -Frame needed

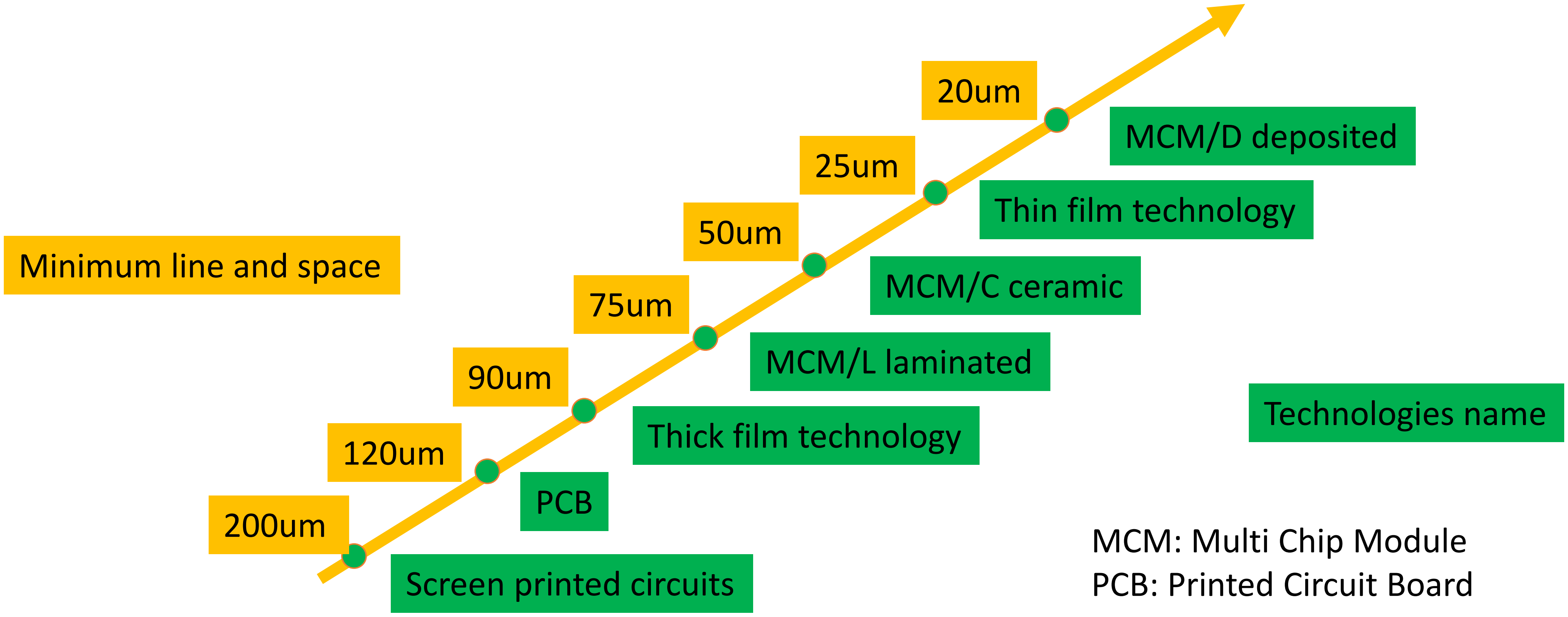
SACLAY



- -Thin patterned copper 5um → still fragile
- -Amplification pillars attached to mesh by process
- -Pillars done by photolithography techniques
- -low yield also → small size also
- -Frame still needed

CERN

Interconnection technologies available at MPT in 1996



Minimum line and space

Technologies name

200um

Screen printed circuits

120um

PCB

90um

Thick film technology

75um

MCM/L laminated

50um

MCM/C ceramic

25um

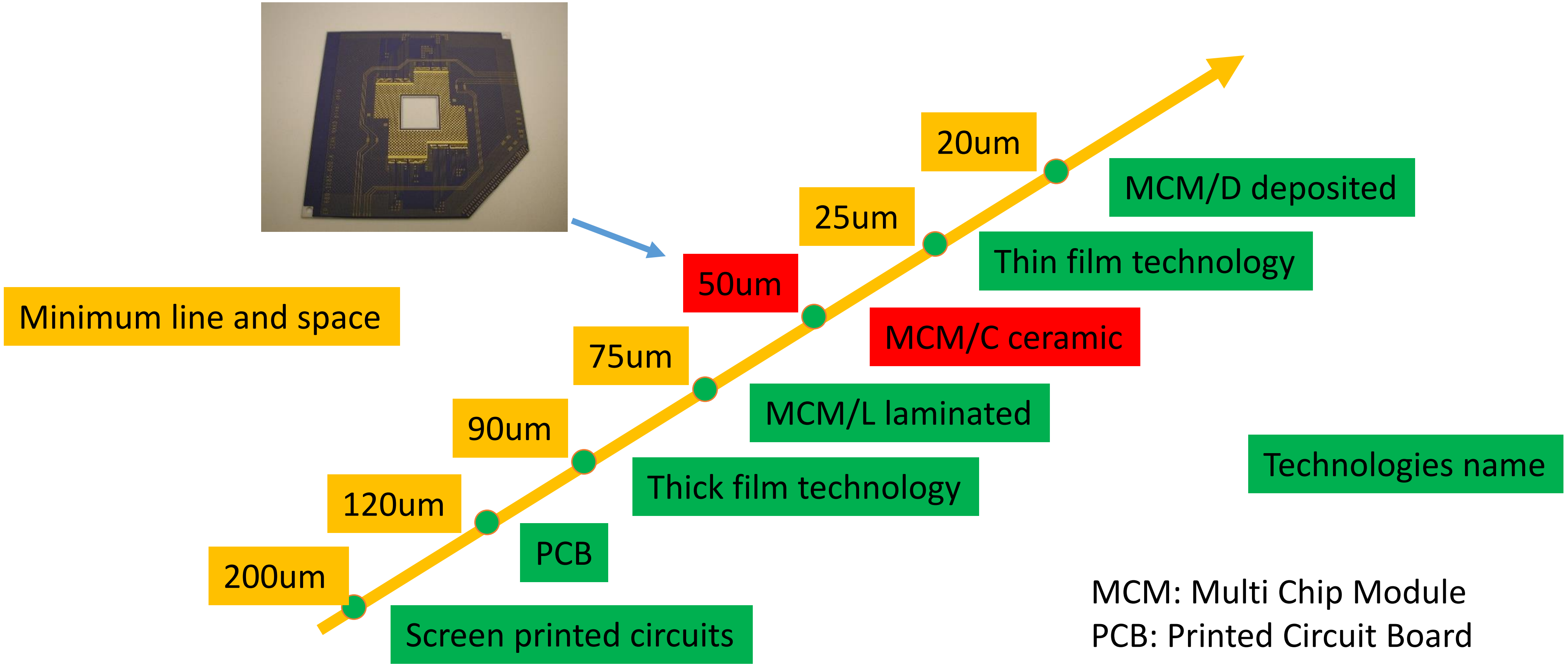
Thin film technology

20um

MCM/D deposited

MCM: Multi Chip Module
PCB: Printed Circuit Board

Interconnection technologies available at MPT in 1996

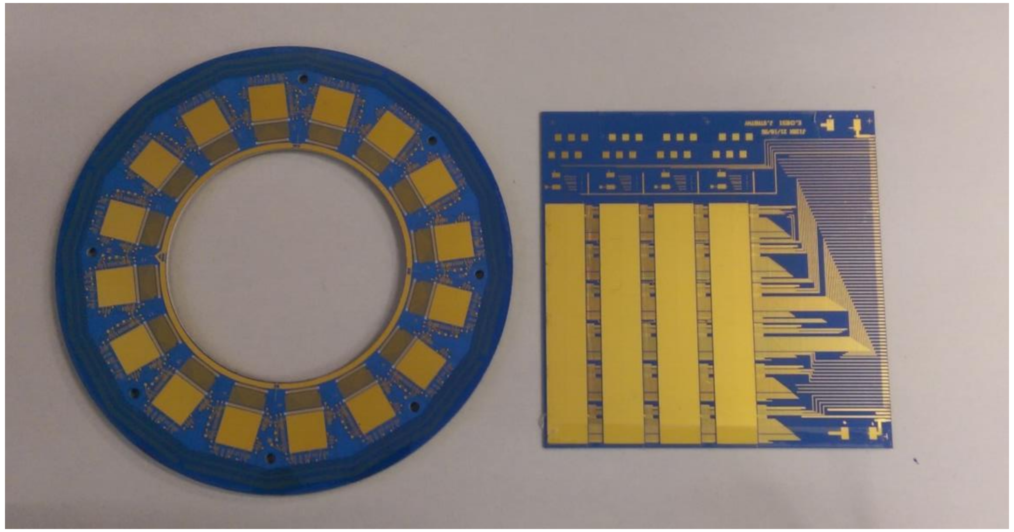


Minimum line and space	Technologies name
200um	Screen printed circuits
120um	PCB
90um	Thick film technology
75um	MCM/L laminated
50um	MCM/C ceramic
25um	Thin film technology
20um	MCM/D deposited

MCM: Multi Chip Module
PCB: Printed Circuit Board

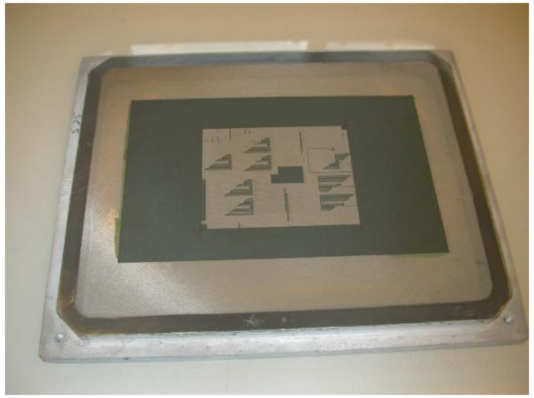
MCM/C

-High density
-High Thermal Conductivity
-Vacuum compatible

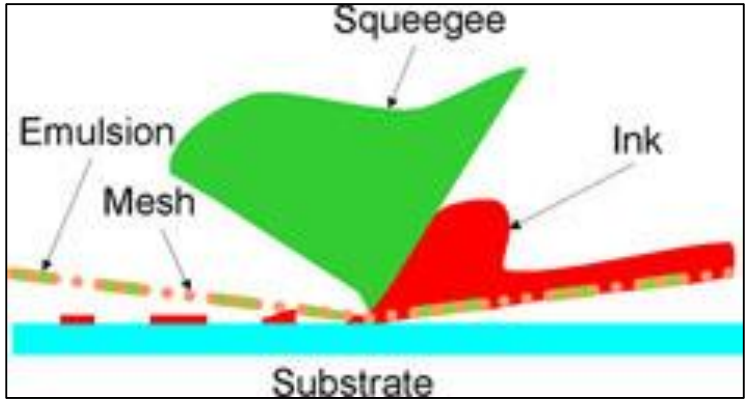


-Conductive Layers: noble metals
-Dielectrics : Ceramic
-Sequentially printed layers
-850 Degrees curing
-Precise deposition
-Small sizes : 20cm x 10cm max

Screen printing machine



Screen with a patterned
Photo-imageable emulsion
on the mesh



Principle

Screen printing is quite common

Semi automatic screen printing machine
Printing area 2m x 0.9m for posters (Satigny)

Manual printing on a T-shirt

THIEME SERIE 3000S - FORMAT IMPRESSION 1500 x 2000 cm

Matériel entièrement reconditionné

Composants électriques, électroniques neufs

Le bâti de la machine est de construction rigide et constituée de profilés acier soudés, usinés et boulonnés. Toutes les parties extérieures sont peintes (peinture époxy).

Le cadre supérieur est commandé électroniquement et se relève parallèlement jusqu'à la position de nettoyage à 350 mm

RACLAGE Inversion pneumatique de la racle et de la contre-racle. Réglage fin de la pression pneumatique de la racle avec mise en parallèle automatique. Les angles de la racle et de la contre-racle sont réglables séparément. Elles sont maintenues à l'aide de fixations rapides, aucun outil n'est nécessaire pour leur montage ou démontage

Les vitesses de raclage et de nappage ainsi que les positions d'arrêt sont programmables sur le pupitre de commande mobile

Afin de s'adapter à la tension de l'écran et à l'épaisseur du support, le hors contact est réglable de 4 à 35 mm sur le pupitre de commande

Le pilotage de l'automate programmable se fait aisément depuis un pupitre mobile.

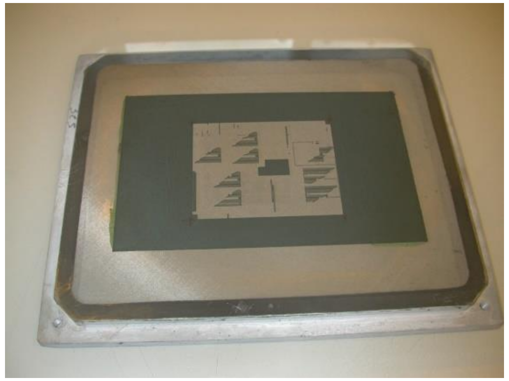
Tous les paramètres requis sont programmés sur un clavier à touches sensitives

FORMAT IMPRESSION 1500 x 2000 cm

Semi automatic CERN machine 1.5m x 2m
General purpose

CERN precision machine 20cm x20cm
for Micro-electronic

Why not using this type of mesh for MM ?



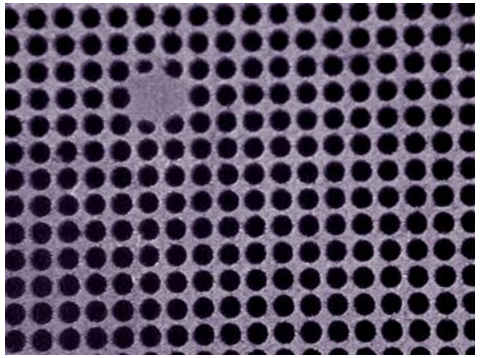
Mechanically robust

Low cost compared to Electroformed or etched

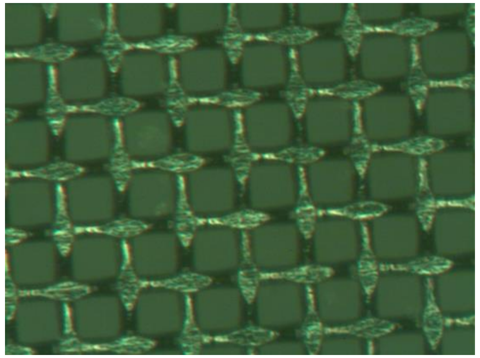
325 wires/inch → wire 24um → transparency 48%
400 wires/inch → wire 18 um → 49%
640 wires/inch → wire 15um → 39%
730 wires/inch → wire 13um → 40%

Available in rolls of 1.2m up to 1.7m

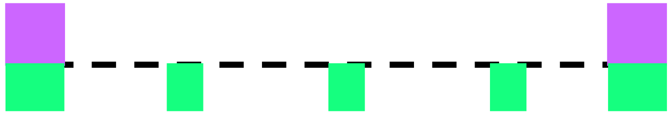
Etched mesh



Woven mesh

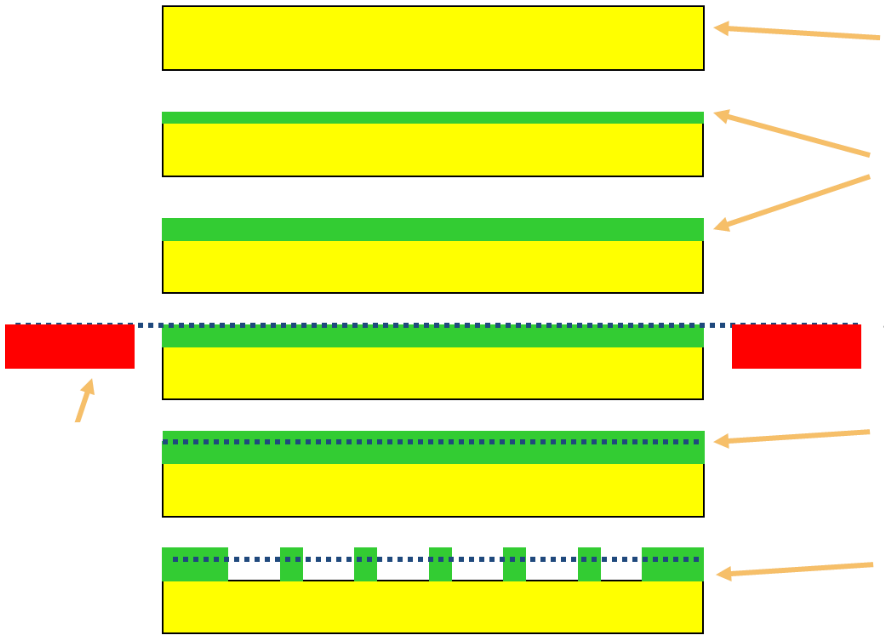


The answer came from Patrick Janneret PHD student
@ Neuchatel university.
Even if the idea was in the air , he was the first to ask us
to put spacing pillars on a woven mesh and test them.
And the results were really good.
This was the important missing detail to go for the next stage.



With I.Giomataris we decided to develop these 2 structures

BULK Micromegas
Developed in 1 week



Read-out board with Cu strips

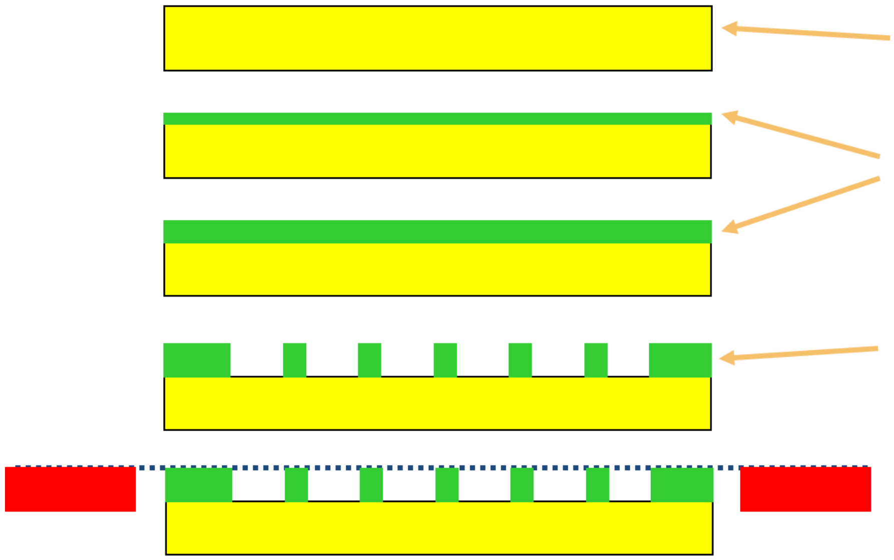
Laminated Photoimageable coverlay

SS Stretched mesh on metal frame

Laminated Photoimageable coverlay

Exposure Development + cure

Floating mesh Micromegas



Read-out board with CU strips

Laminated Photoimageable coverlay

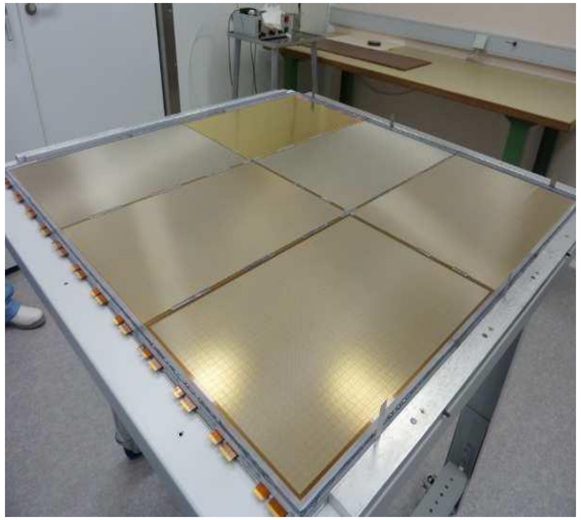
Exposure Development + cure

SS Mesh on metallic frame

The detectors behavior were really good !
The technology spreading was quite rapid

BULK Micromegas detectors

T2K TPC ,J.Beucher
1.8m x 0.8m plane
With 12 detectors



ILC DHCAL , M.Chefdeville
1m x 1m plane
With 6 detectors

ATLAS NSW R&D, Joerg Wotschack
1.5m x 0.5m plane
Single panel
Muon detector in LHC background

But during the early phase of ATLAS NSW R&D we rapidly faced a big problem.

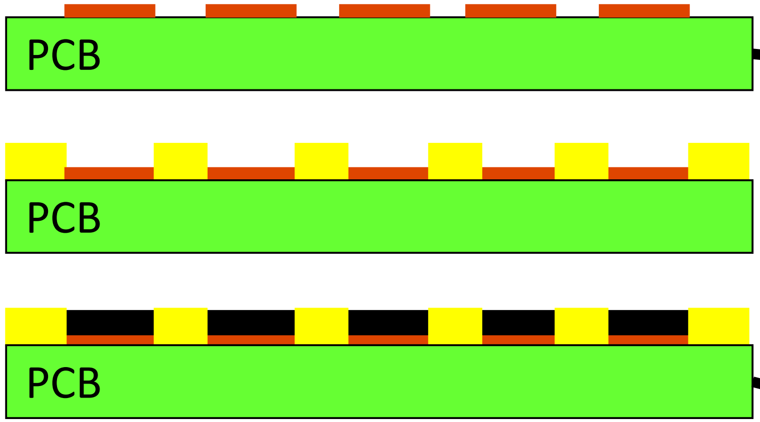
In presence of LHC background the detectors were continuously sparking , compromising seriously the use of this technology in HEP applications .

In close collaboration with Joerg Wotschack we decided to add resistive layers.

It took us 12 iterations to understand how to use resistive layers

R1-R2-R3-R4-R5-R6-R7

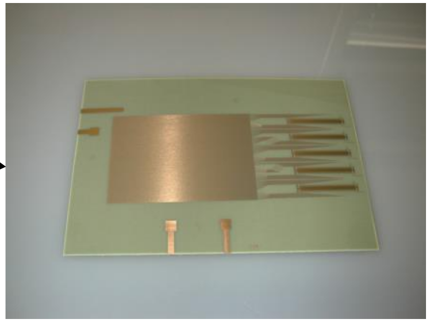
Resistive layer directly on R/O lines

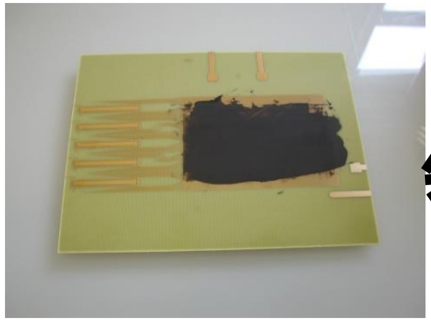


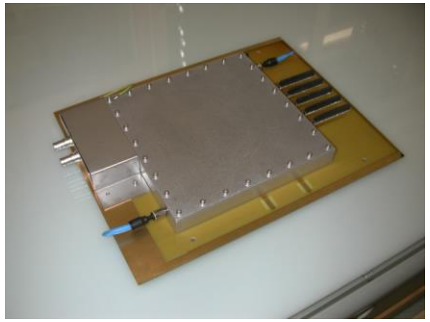
Several resistive values and
Shapes have been tested

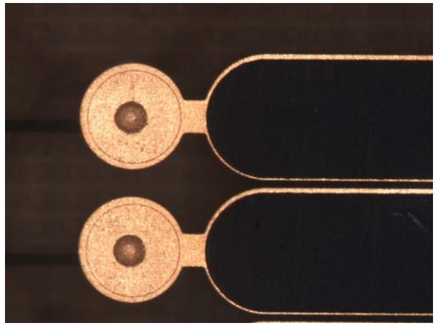
Test : apply a voltage above the
breakdown voltage of the gas (Air), with
a really high current limitation (10mA)

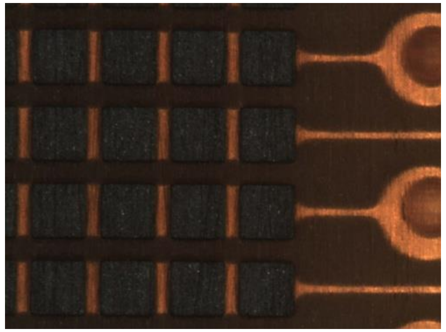
All detectors died within a sec !
-Vertical resistive layer breakdown
-and massive Mesh melting

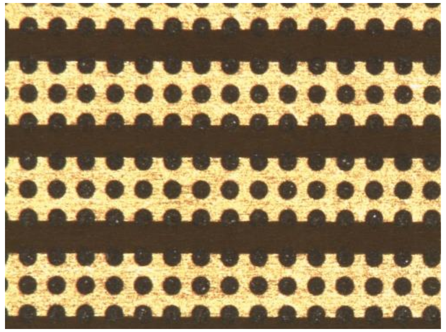




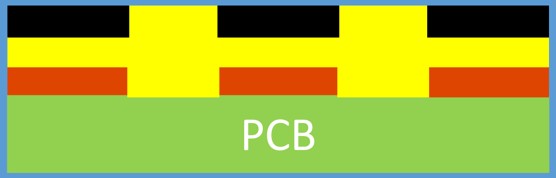






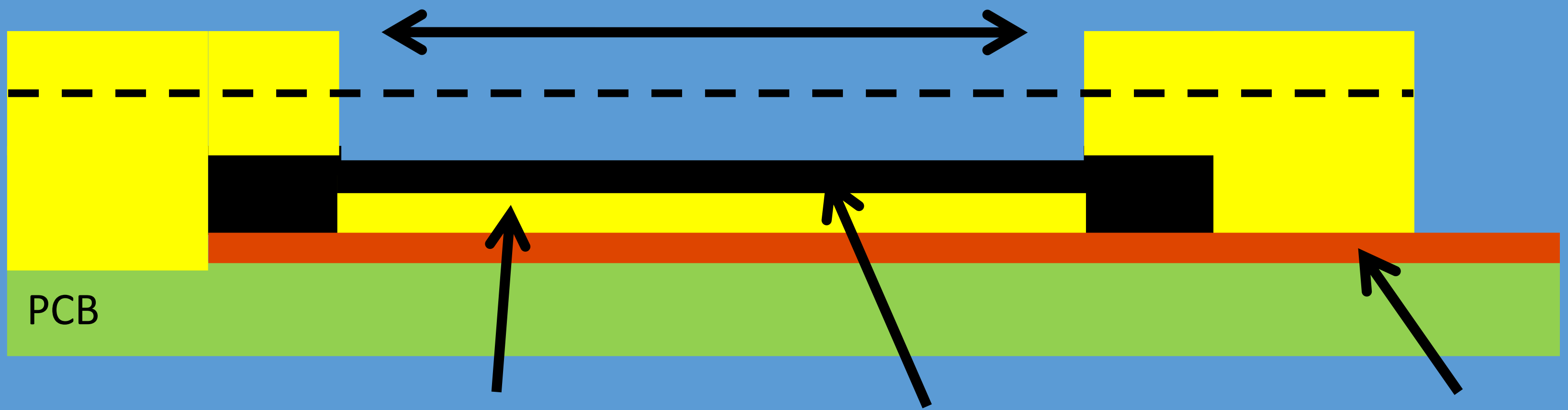


Then R9-R10



Cross section

Active area 100mm

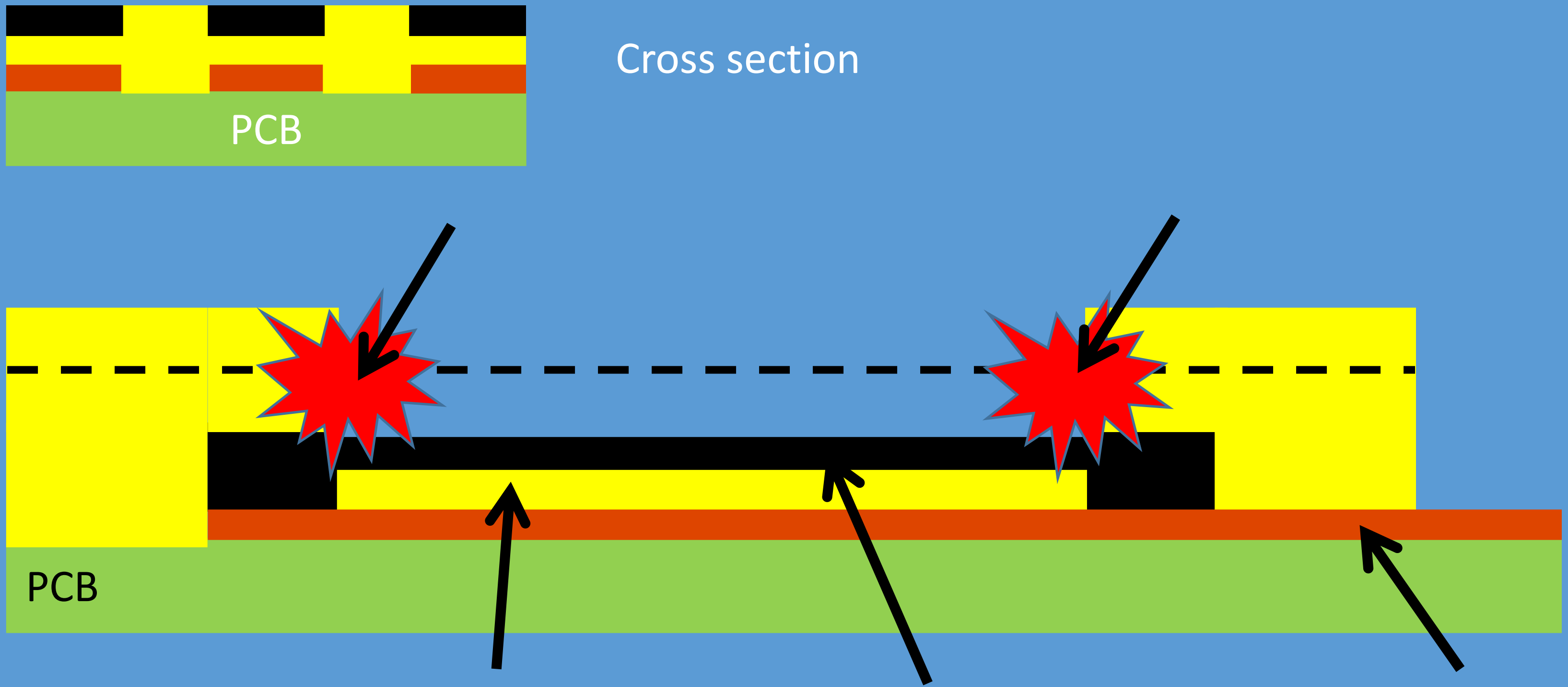


Coverlay
65um

Resistive Strip
1MOhms / cm

Copper Strip 0.15mm
x 100mm

Then R9-R10



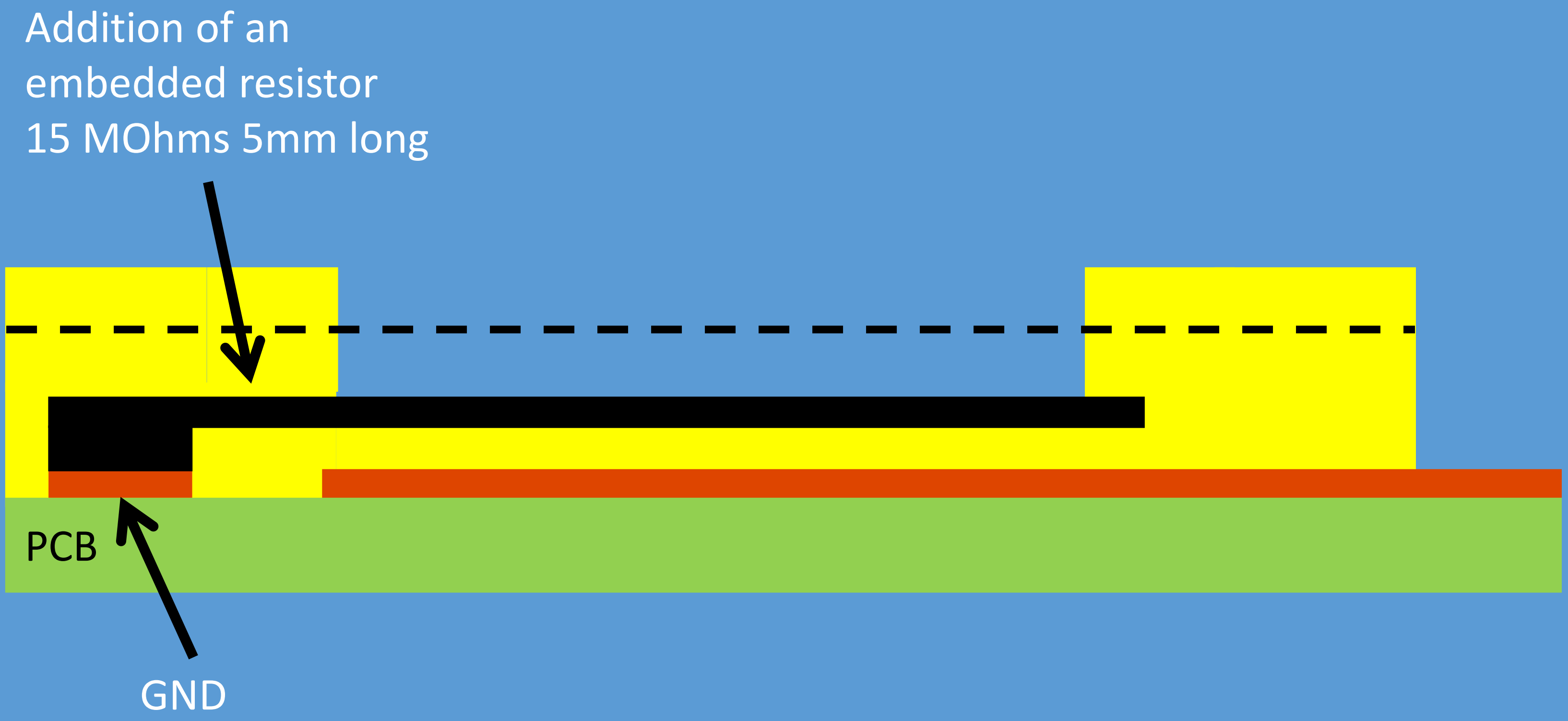
Coverlay
65um

Resistive Strip
1MOhms/cm

Copper Strip 0.15mm
x 100mm

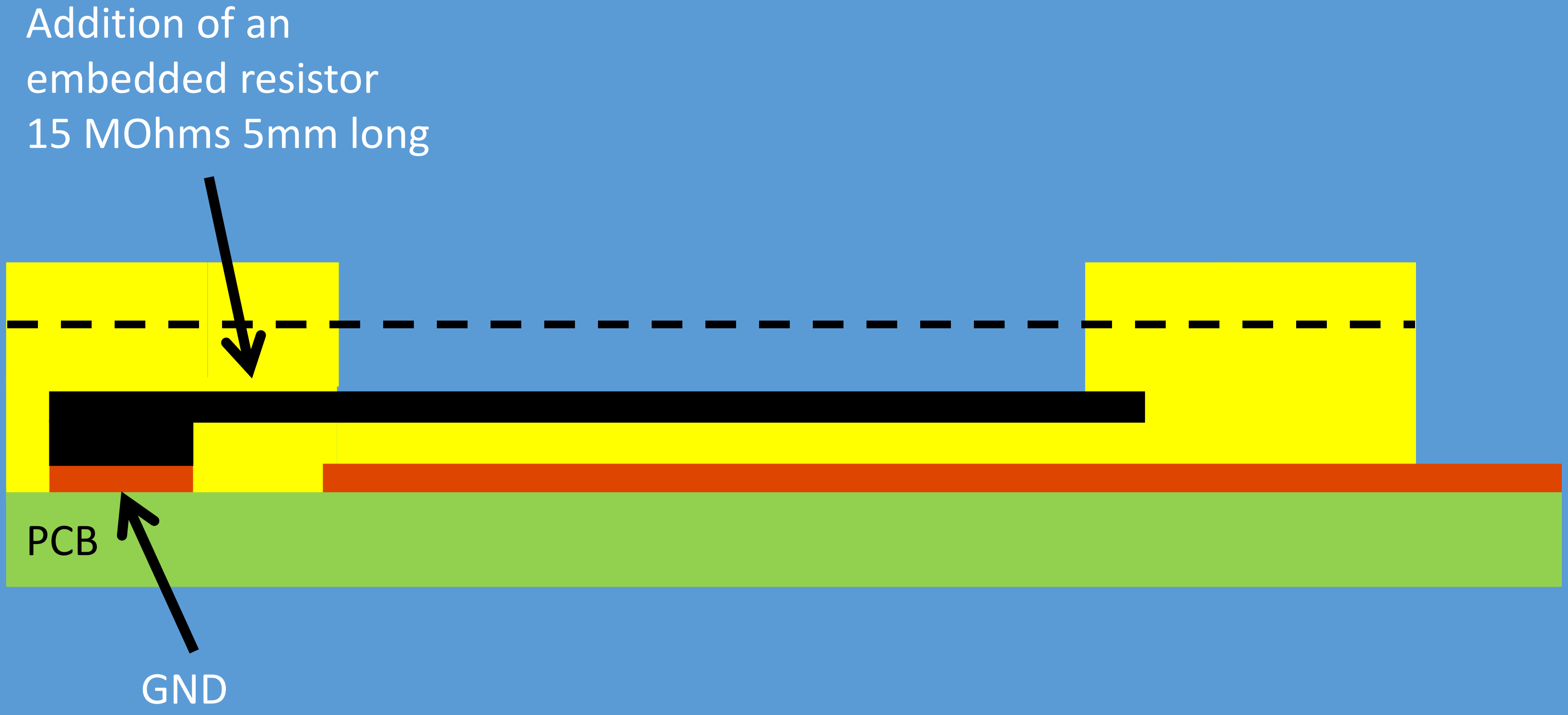
For the fist time a structure survived our test for more than 1mn.
We have anyway been able to damage the detectors .
Damages were always near the connection between resistive strip and copper strip.

And finally R11-12



Addition of an
embedded resistor
15 MOhms 5mm long

And finally R11-12


Addition of an
embedded resistor
15 MOhms 5mm long

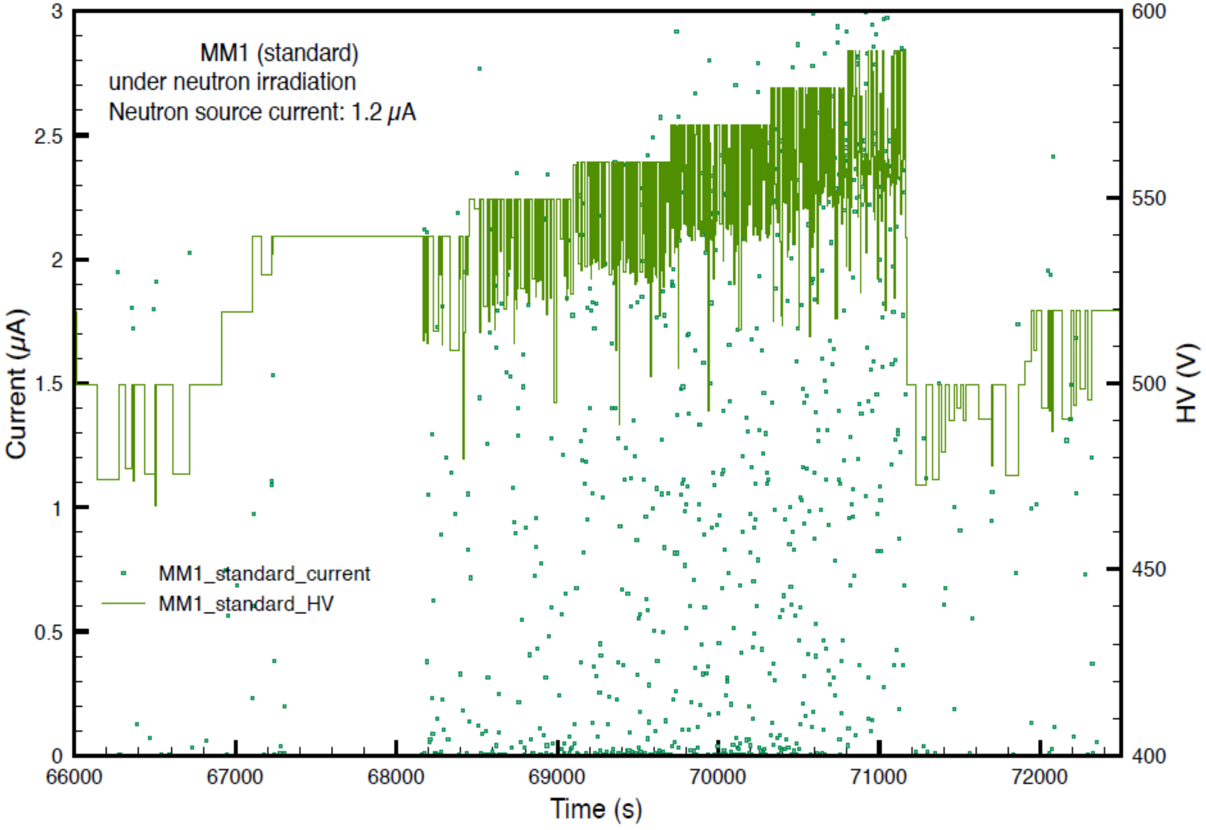
PCB

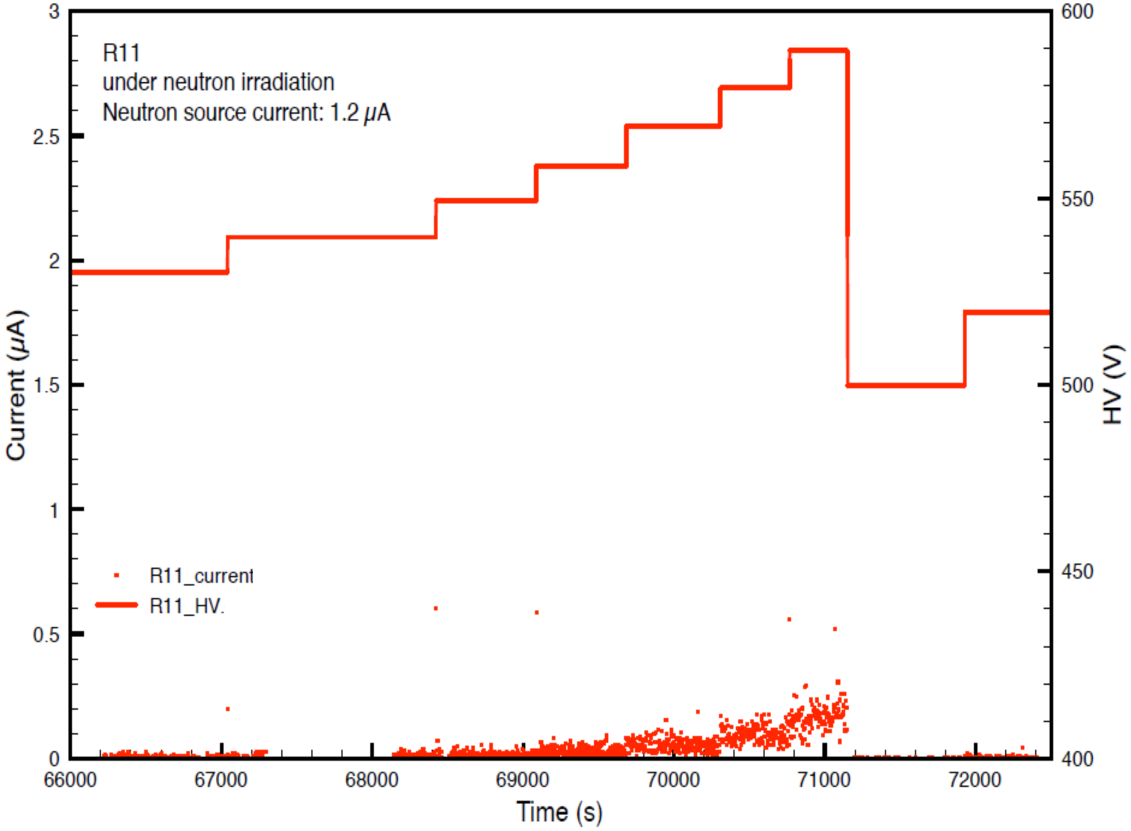
GND

Perfect behavior, sparks were quenched
This helped us to validate our electrical model of the spark mechanism

Validation with Neutron irradiation on R11-R12

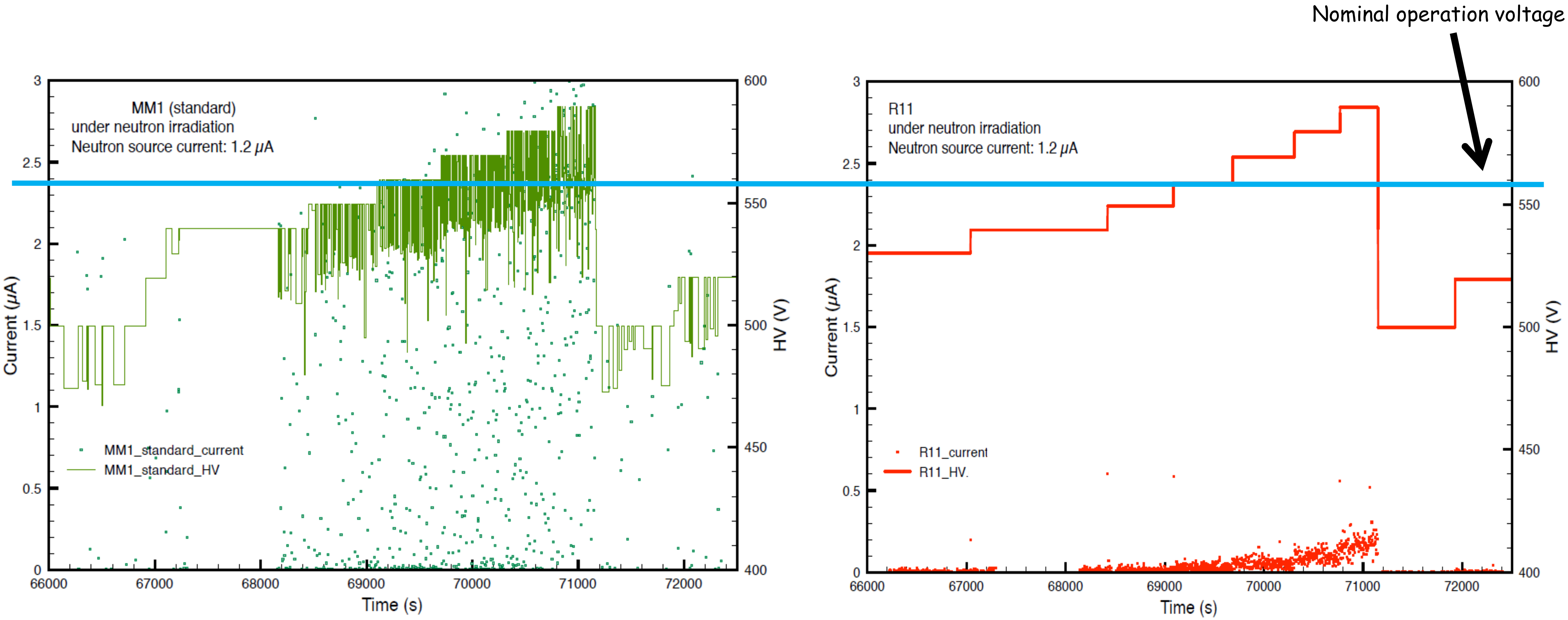
(protons effect)





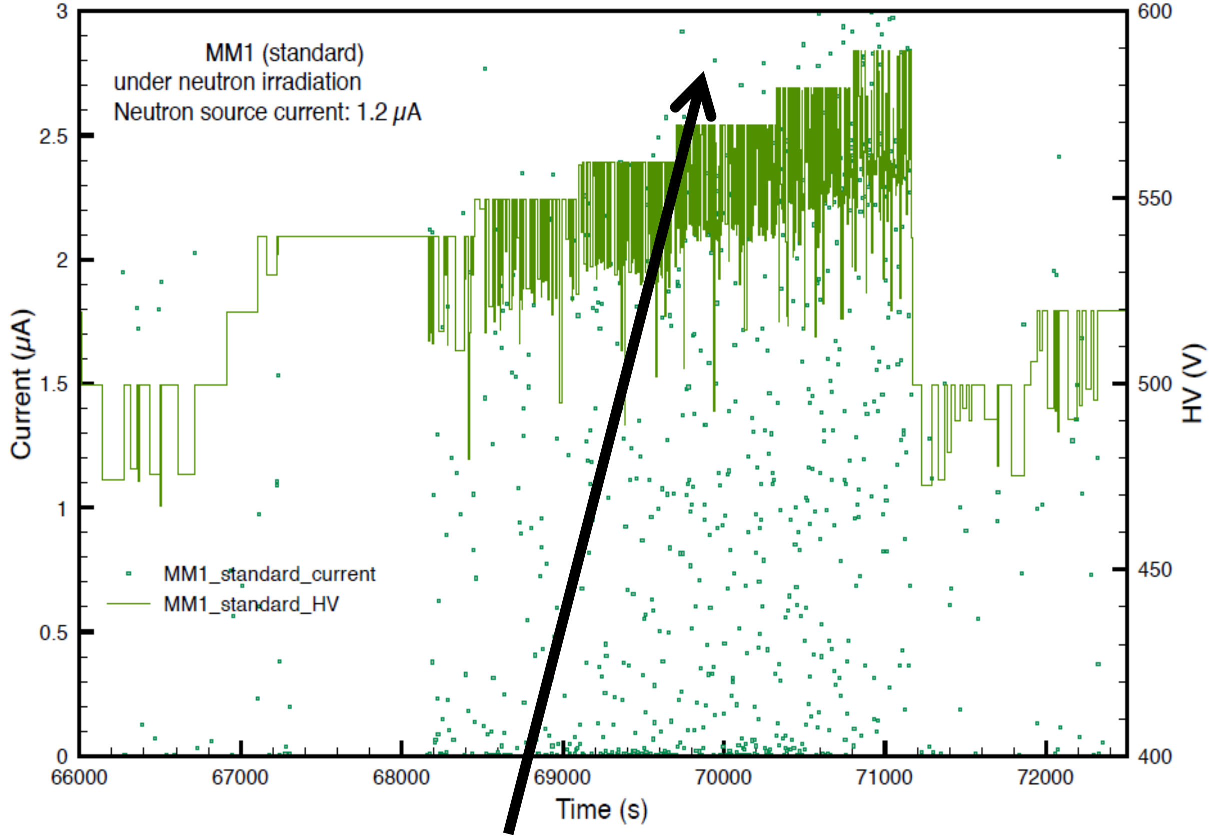
Validation with Neutron irradiation on R11-R12

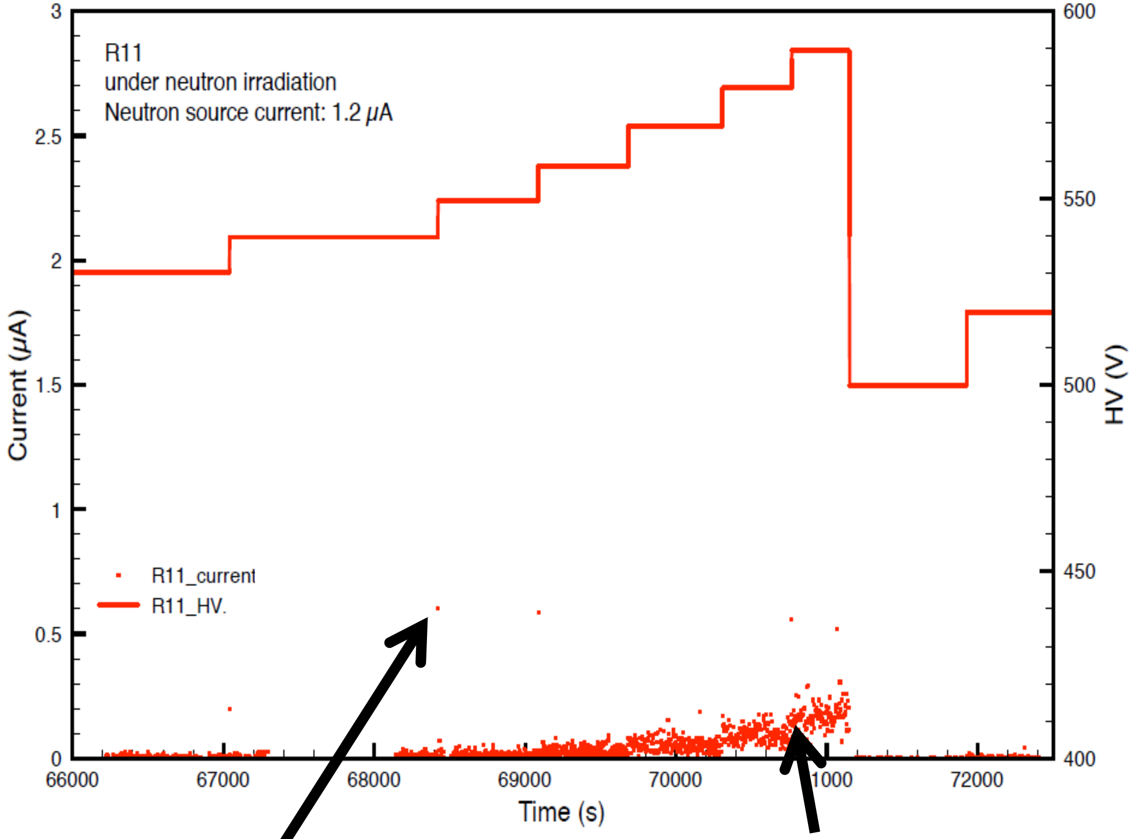
(protons effect)



Validation with Neutron irradiation on R11-R12

(protons effect)





Peak current limited by the power supply
Increasing the current limit increases the peak currents
The real situation is even worse than this plot

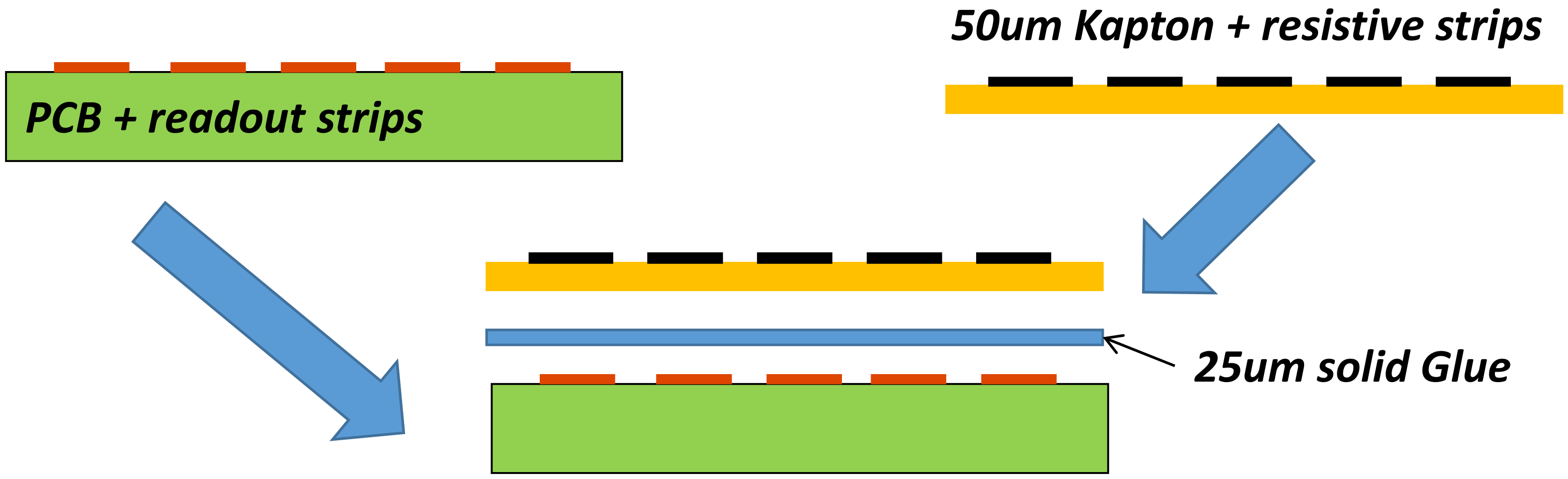
Current peaks due to voltage ramp up

Peak current is limited by the detector itself

ATLAS NSW prototype production

PCB + readout strips

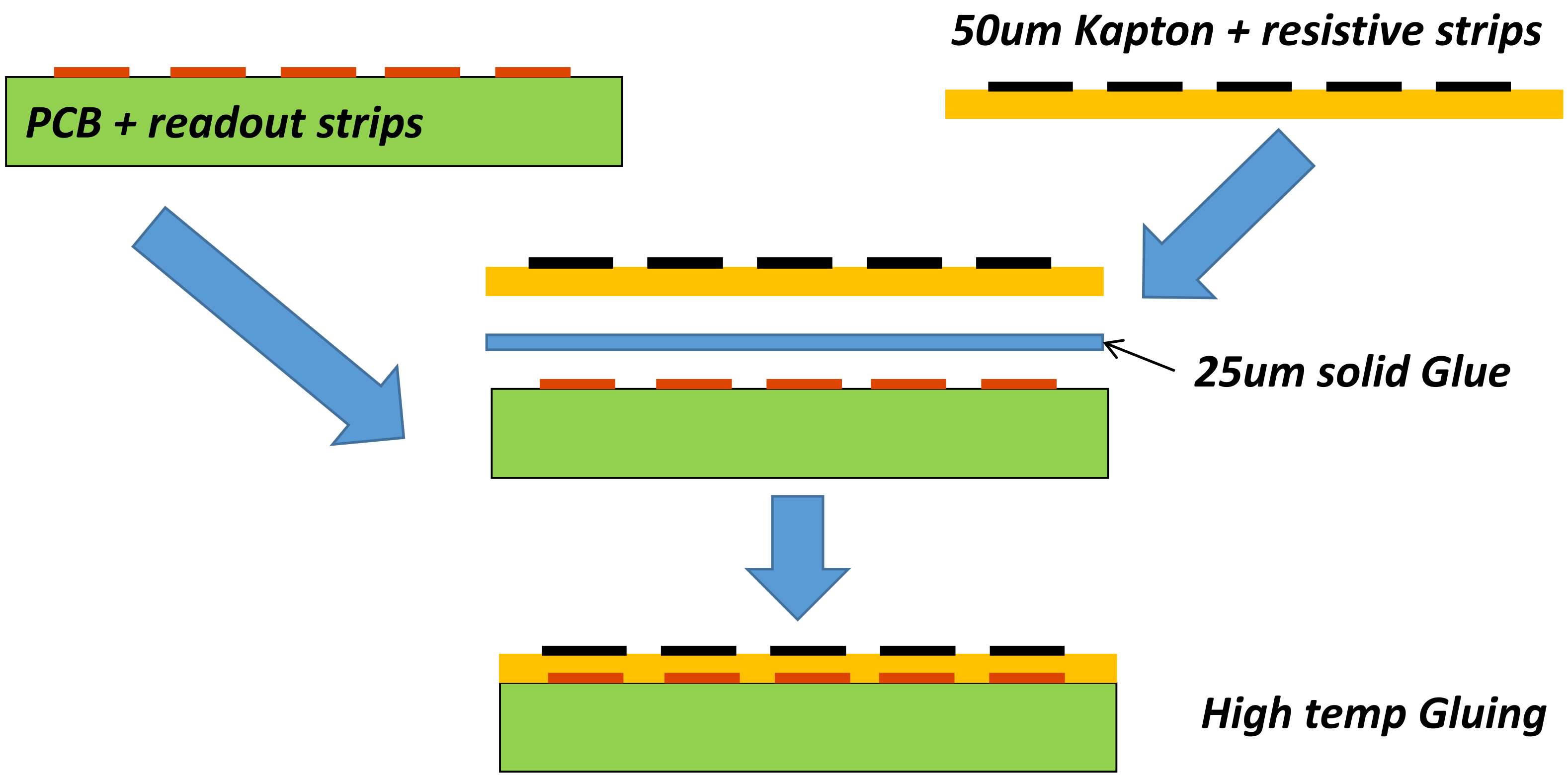
50um Kapton + resistive strips

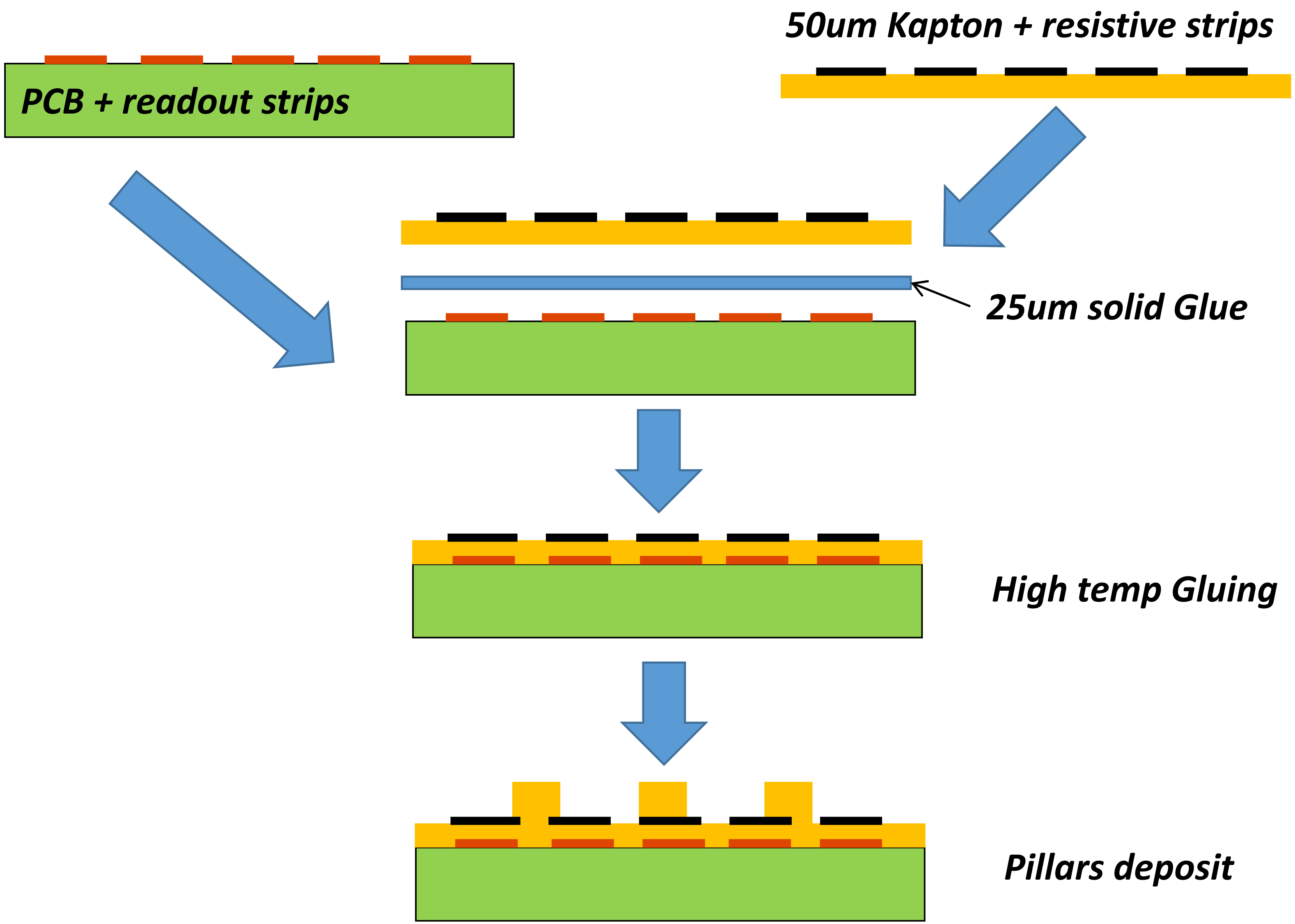


PCB + readout strips

50um Kapton + resistive strips

25um solid Glue


50um Kapton + resistive strips
PCB + readout strips
25um solid Glue
High temp Gluing



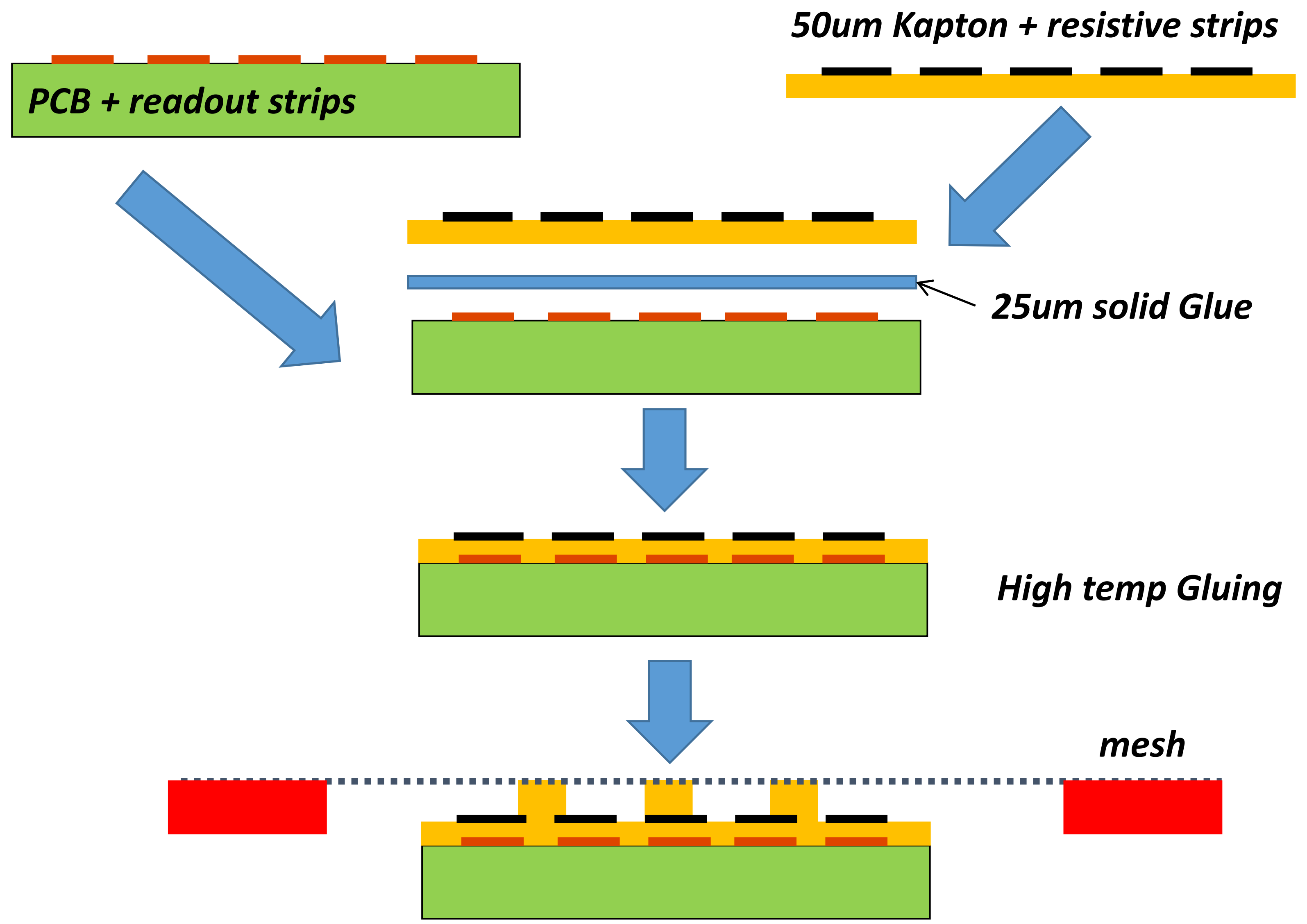
50um Kapton + resistive strips

PCB + readout strips

25um solid Glue

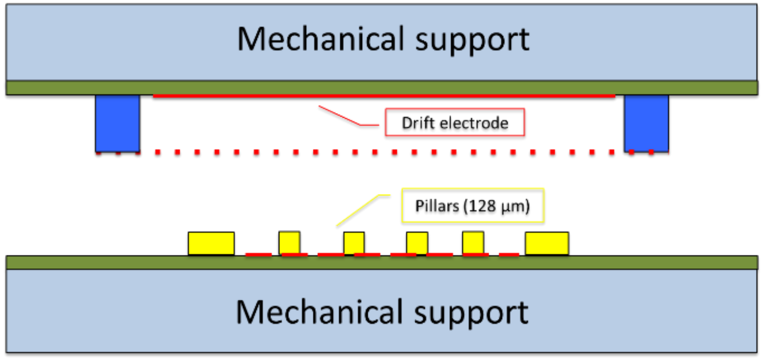
High temp Gluing

Pillars deposit


50um Kapton + resistive strips
PCB + readout strips
25um solid Glue
High temp Gluing
mesh

Real ATLAS NSW prototype 1m x 2m

Open



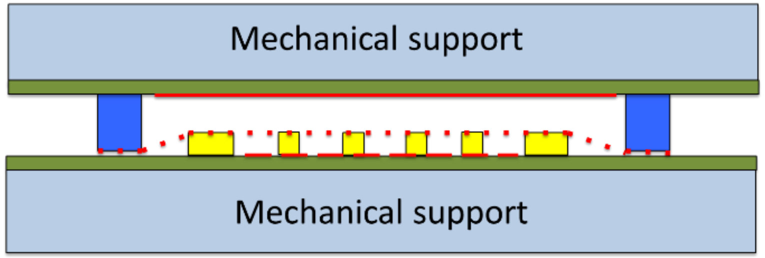
Mechanical support

Drift electrode

Pillars (128 µm)

Mechanical support

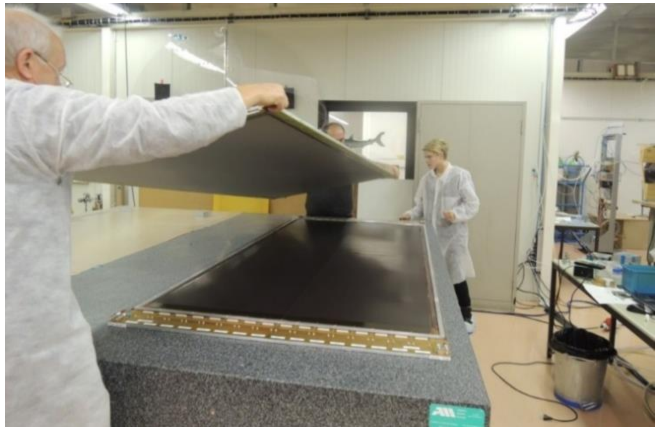
Closed



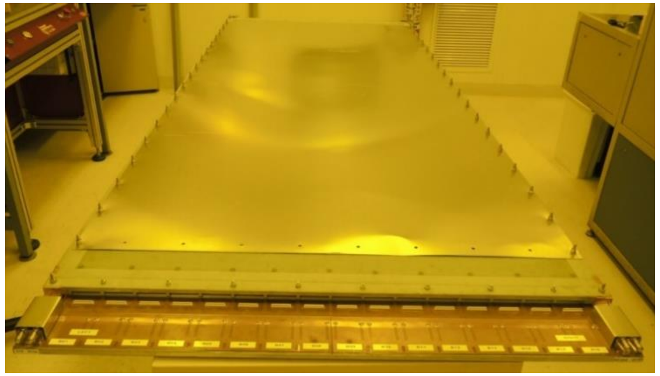
Mechanical support

Mechanical support

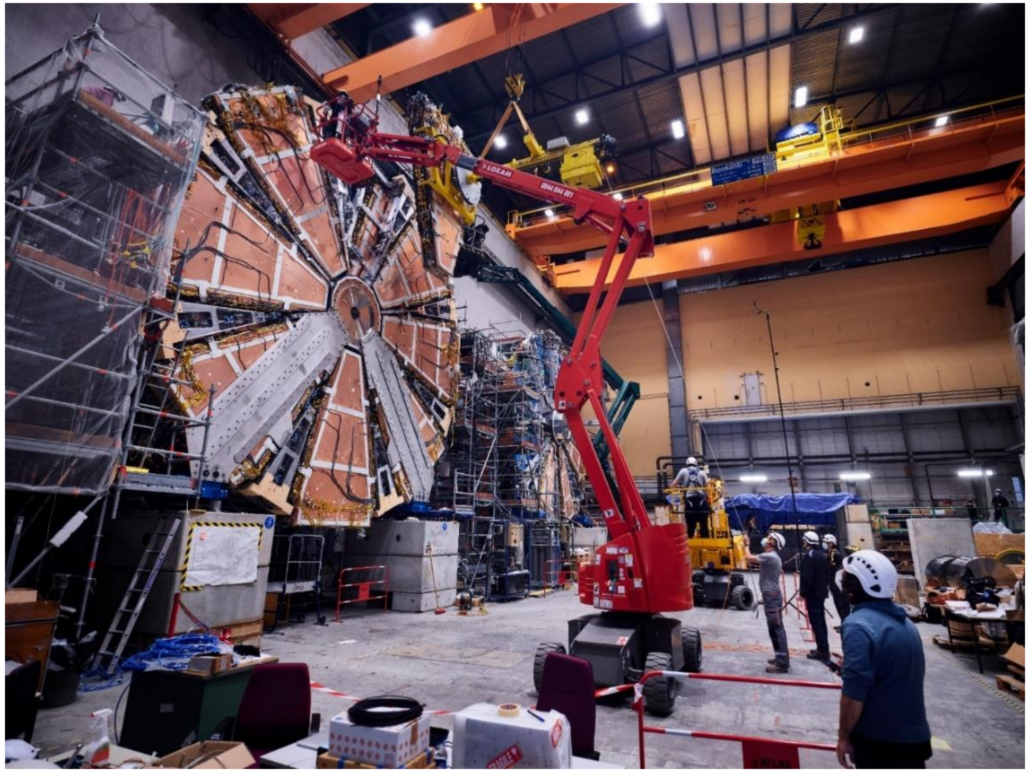
Open



Closed



Atlas NSW



Close to 2000 Micromegas detectors produced with sizes up to 2m x 0.5m

PCBs with pillars built at ELTOS (IT) and ELVIA (FR)
Panels construction and detector Assy :
- -Dubna
- -INFN Frascati
- -CEA Saclay
- -LMU Munich

MPT participated largely to the R&D and was also involved in the mass production with industry
- -Specification
- -Companies selection
- -Technology transfer

Unfortunately for other applications, we were really limited with resistive values obtained by screen printing.

So the last evolution is the introduction of Vacuum deposited resistive DLC layers (Diamond Like Carbon).

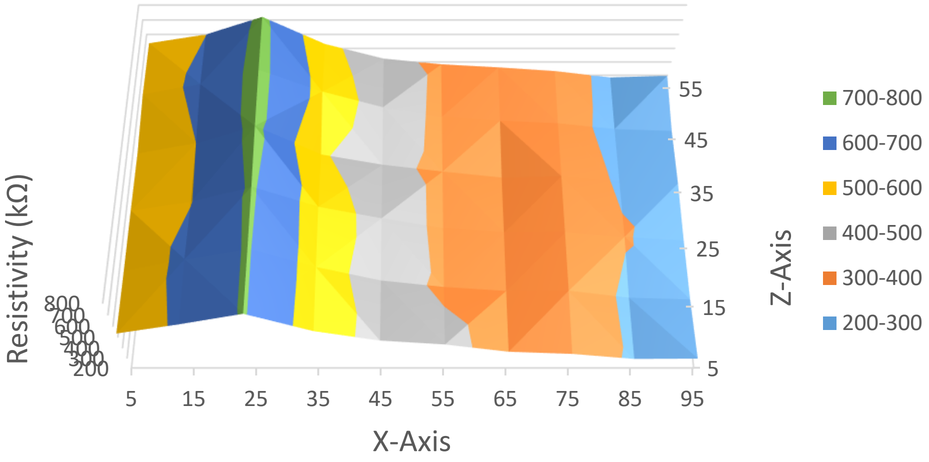
This is the result of a large collaboration effort :

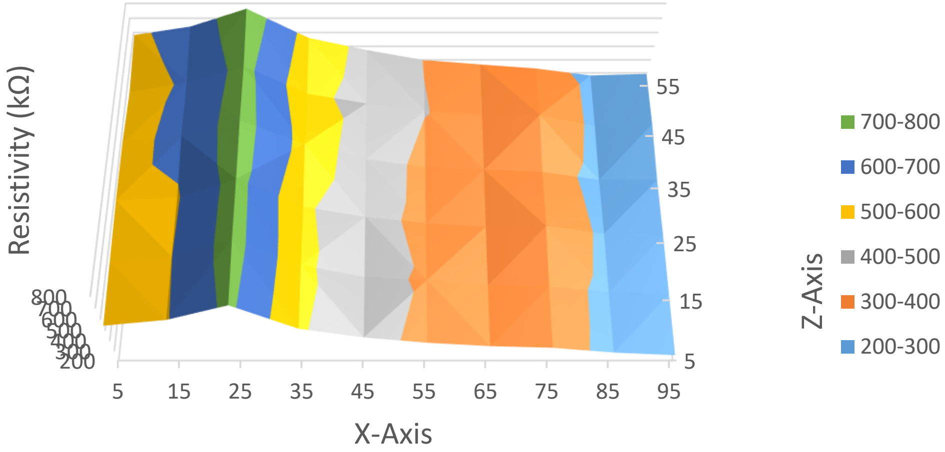
We can now access nearly all resistive values (from kOhms to Gohms per Square) .

Kobe

ESS

China USTC





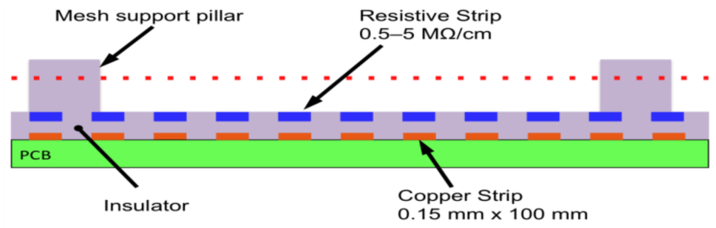
Initial results: example of 1m x 0.6m foils 500Kohms/square +/-60%
The error dropped today to values around +/- 30%

DLC brought new capabilities:

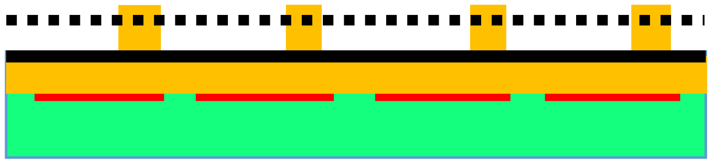
Possibility to make 2D Micromegas detectors.
Spark protection improvement.
Possibility to make High rate resistive detectors.
Better granularity thanks to the resistive spreading effect.
Removed the need of electronic FE protections.

High rate resistive Micromegas

Medium rate detectors 100kHz/cm2
Side evacuation of the charges



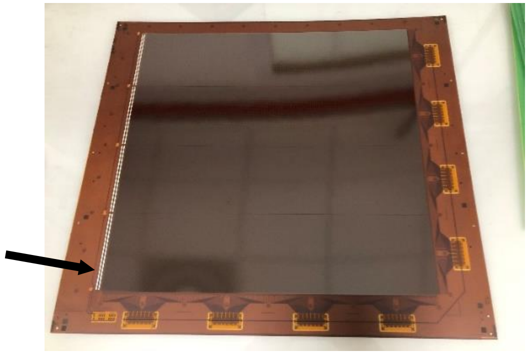
- Single layer screen printed strips



- 1 DLC layer without pattern

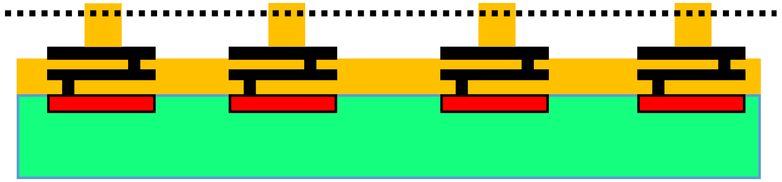
LSBB
50cm x 50cm
X/Y 1mm/1mm
30M/Sqr DLC layer

Silver line evacuation



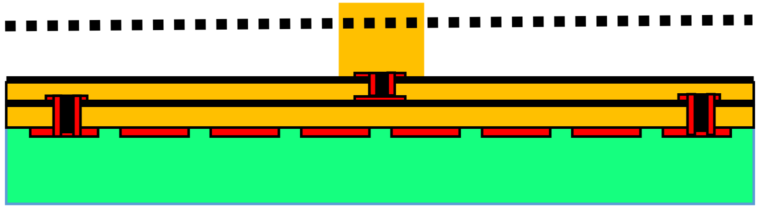
High rate detectors 10Mhz/cm2
Charge evacuation inside active area

Printed



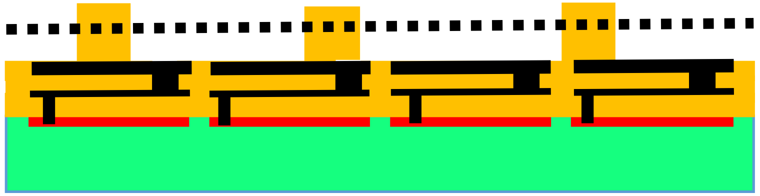
- 2 layers screen printed pads

DLC
Best results



- 2 DLC layers without patterns

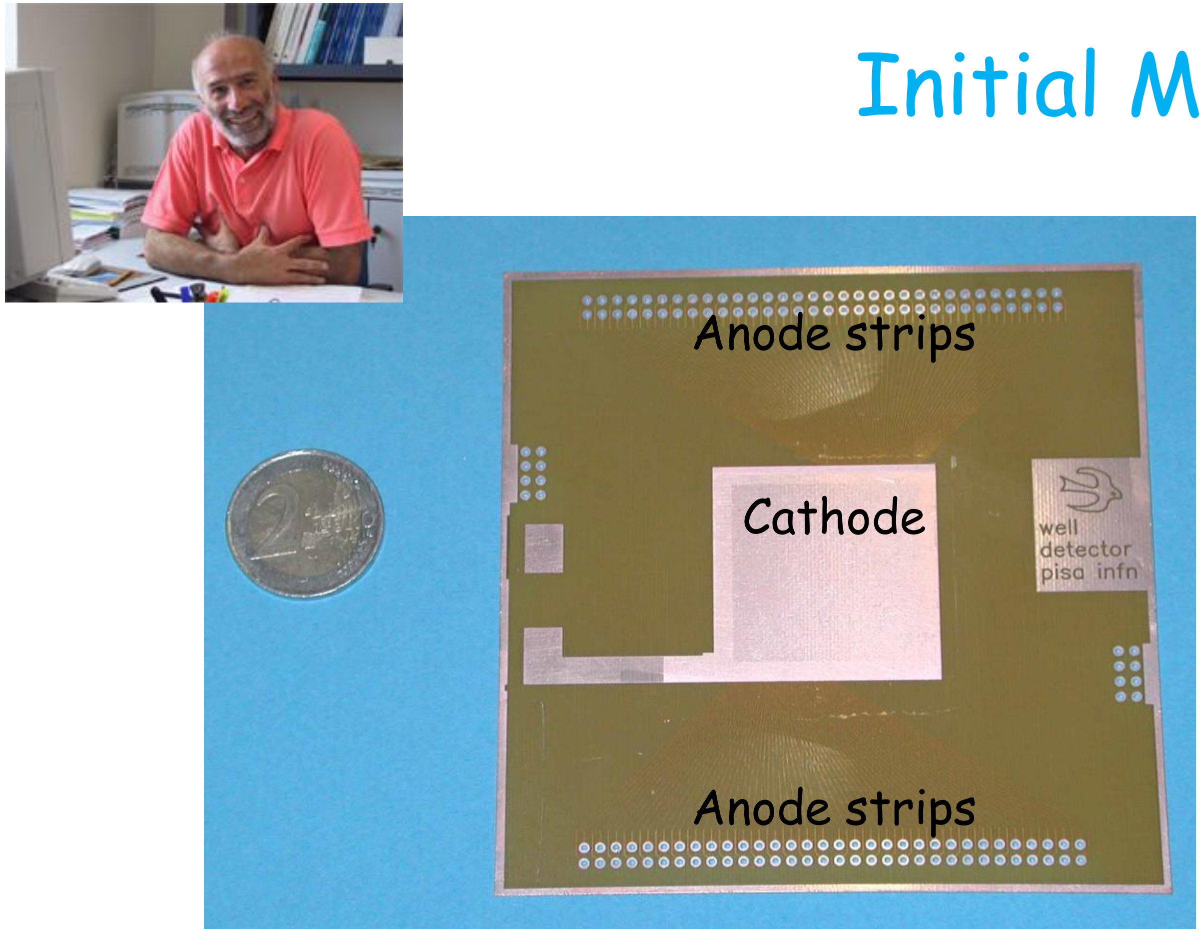
Mix

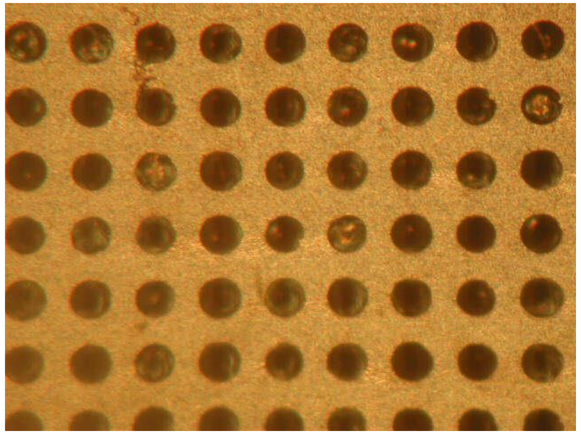


- DLC and screen printed pads

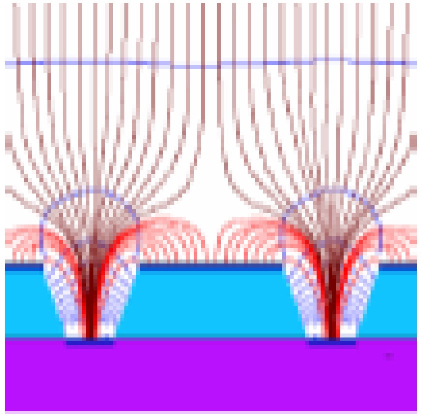
uRwell
Result of all the accumulated knowhow

Initial Micro-well

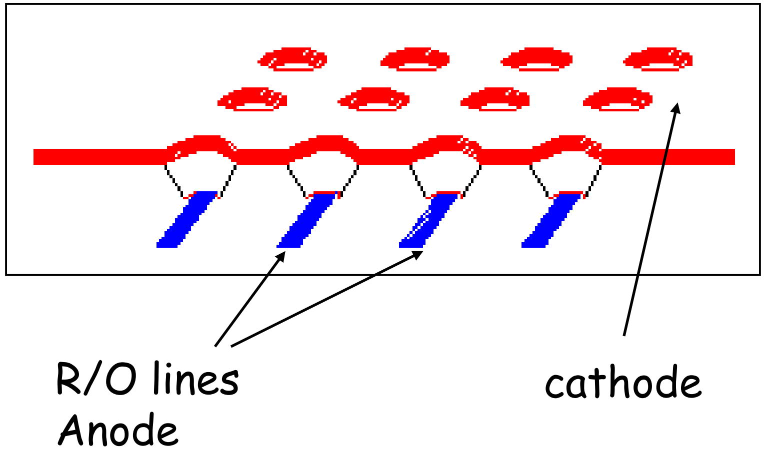




Close-up view
Square pattern used
in the early days

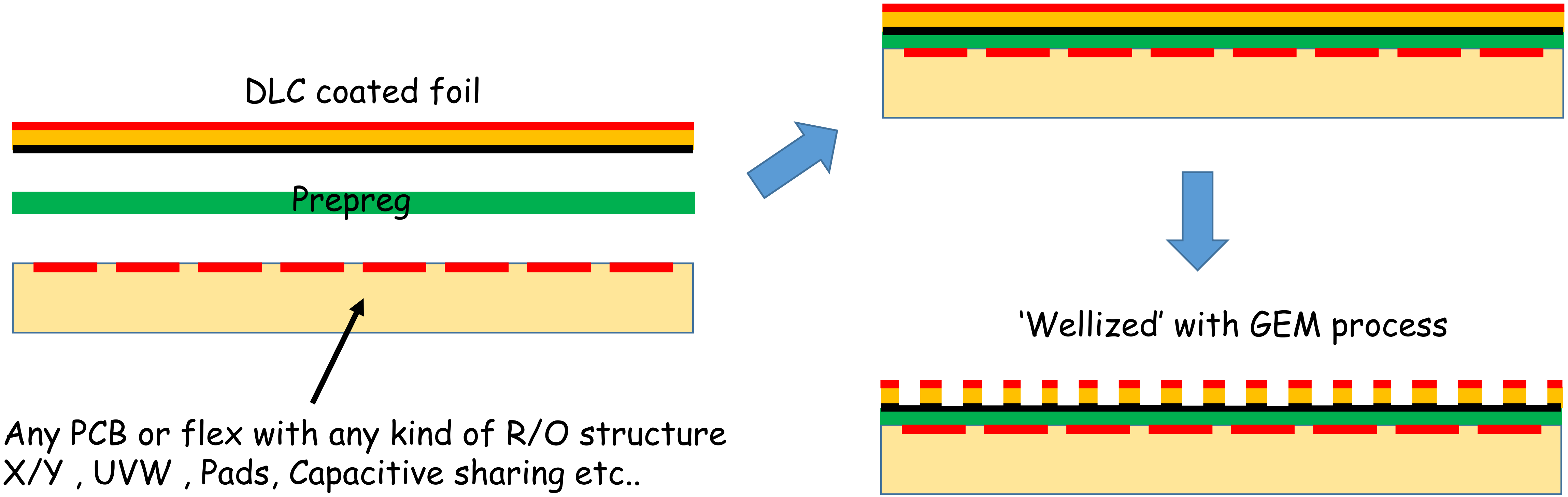


groove/well



- -3 x 3 cm Micro-well detector
- -Ronaldo Bellazzini idea 1997
- -Produced at MPT with GEM processes
- -Really simple but abandoned due
to the impossibility to mitigate spark damages

15 years later: introduction of a resistive layer to control the sparks thanks to MM experience!



DLC coated foil

Prepreg

Any PCB or flex with any kind of R/O structure
X/Y , UVW , Pads, Capacitive sharing etc..

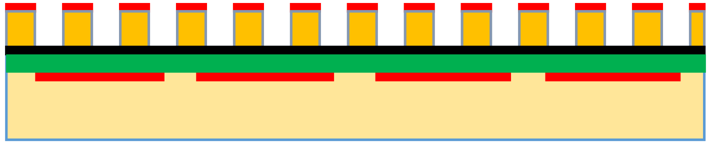
After vacuum gluing

'Wellized' with GEM process

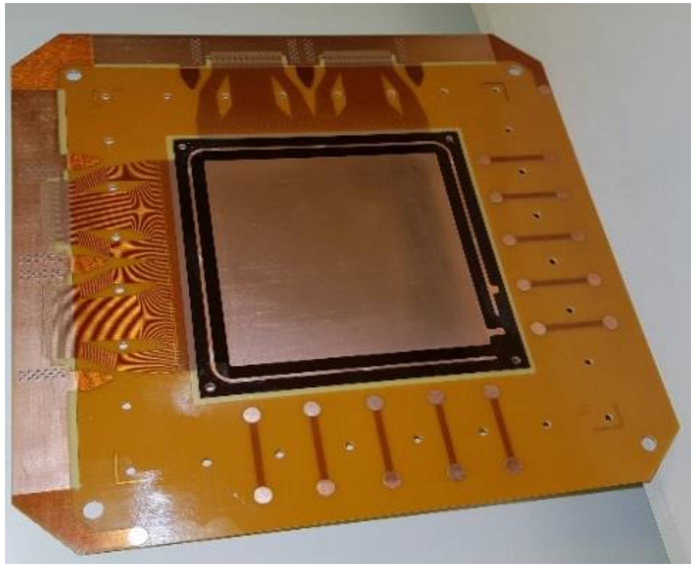
We have then explored different ways to improve the rate capability

<u>Medium rate μRwell</u>

Lateral evacuation of charges



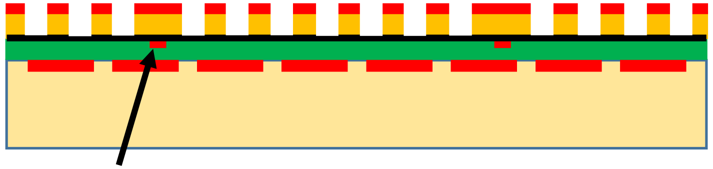
- 1 DLC layer



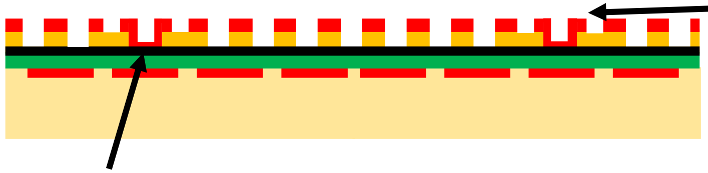
10cm x 10cm μRwell detector
"STD kit"

<u>High rate uRwell</u>

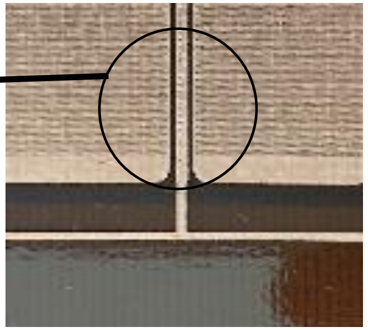
Charge evacuation in the active area

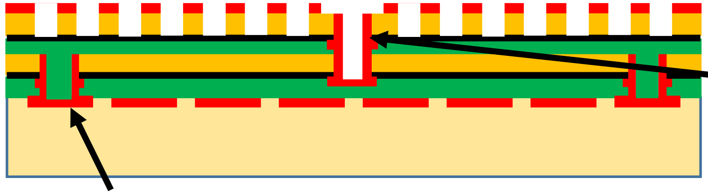


- DLC connected with Cu strips on the DLC

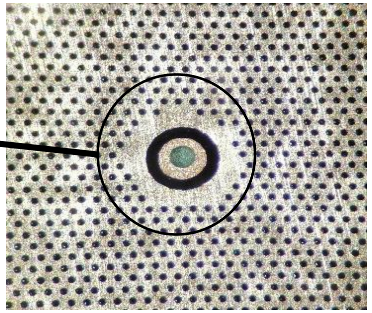


- DLC connected by plated grooves or holes

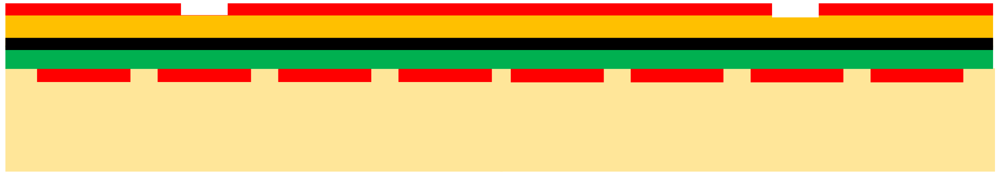




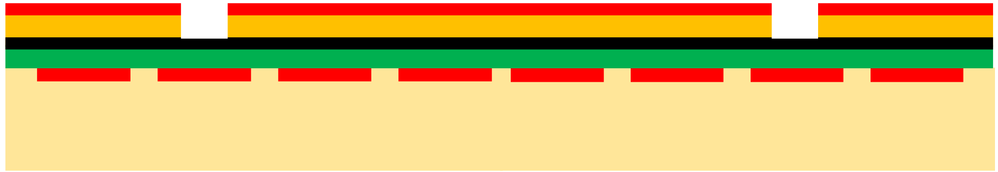
- 2 DLC layers connected by plated holes



Best compromise between performances & cost → PEP

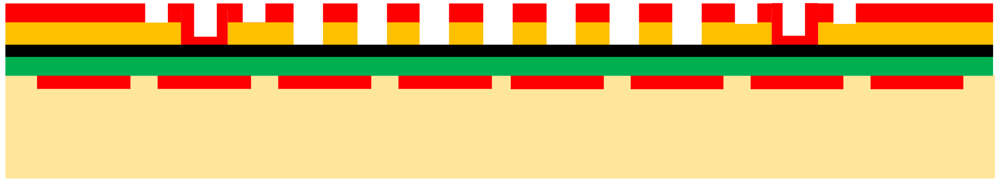


P→ Pattern top copper



E→ Etch the kapton

P→ Plate with copper



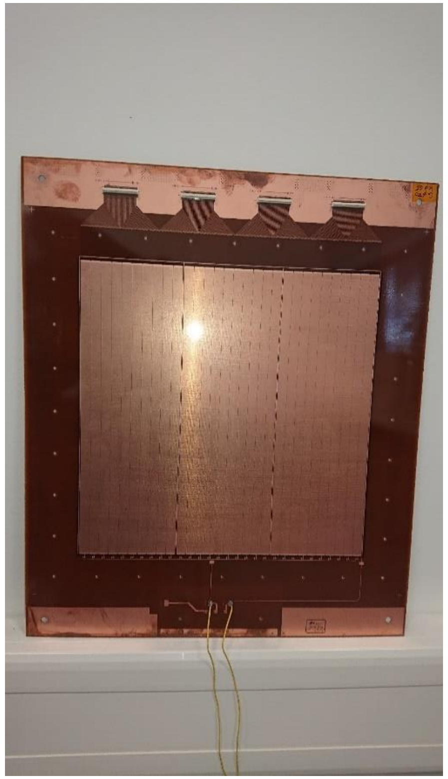
Wellize

uRwell advantages

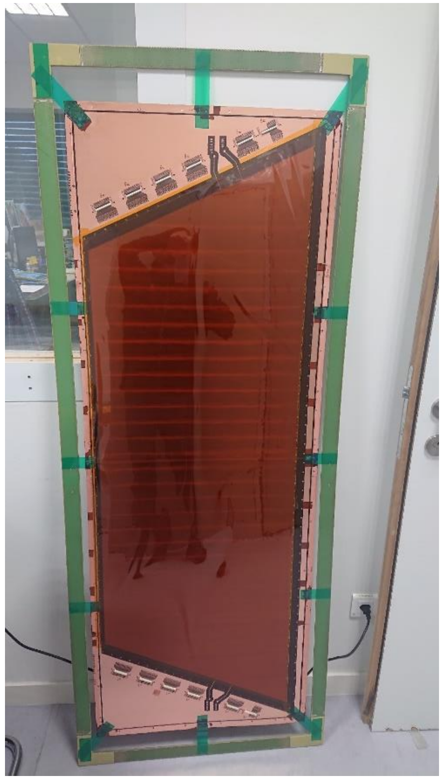
- Total control of the released energy during a spark.
- The control is so good that we can use the sparks to clean the detectors ! → We call it "E-cleaning"
- The simplest uRwell is flexible → cylindrical detectors are easy to produce.
- Low mass , low background
- First time we have a detector production process fully compatible with mass production tools from PCB industry.
- We are aiming to reach a point were one can buy a uRwell as a STD PCB (Technology transfer on going)
- Lower cost than GEMs or resistive MM

PEP examples

Frascati R&D
1D PEP uRwell
Active area:
40cm x 5cm



Frascati R&D
1D PEP uRwell
Active area:
30cm x 30cm



CLAS12 R&D
2D PEP uRwell
Active area:
150cm x 50cm

CLAS12 uRwell
rolled in the oven
for E-cleaning

Future

- Vacuum deposition
- Subtractive micro-structuring
  - Chemical
  - Laser
  - Reactive Ion Etching Plasma (RIE)
  - Directive RIE Plasma (DRIE)
- Additive micro-structuring
  - 3D printing

Pulsed DC magnetron reactive vacuum deposition machine @CERN

- Max foil size:
  - -1.7m x 0.7m.
- Useful size:
  - -1.7m x 0.6m.

- Can deposit
  - -metals
  - -Dielectrics
  - -alloys
  - -Carbon structures

- 5 targets.
- 3 simultaneous deposition.
- 3 gas inputs for reactive deposits:
  - H_2,N_2,0_2,C_2H_2,Ar etc..
- 300 deg in built heater.
- In built plasma cleaner

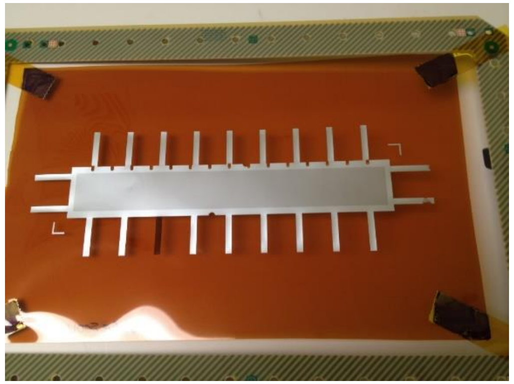
- Budget:
  - -25% INFN
  - -25% CERN EP/DT group
  - -50% MPT self financing

- Market survey → 04/21
- Invitation to tender → 05/21
- Purchase order → 08/21
- Delivery → 10/22
- Operation → 11/22

- Fantastic help during from:
  - DLC collaboration team

Future Program for our vacuum deposition machine

Aluminum GEM



-Aluminium GEMs

-Low mass detectors

-Continue to explore DLC possibilities

-Improve Uniformity : target → less than +/-5% error (1m x0.6m)

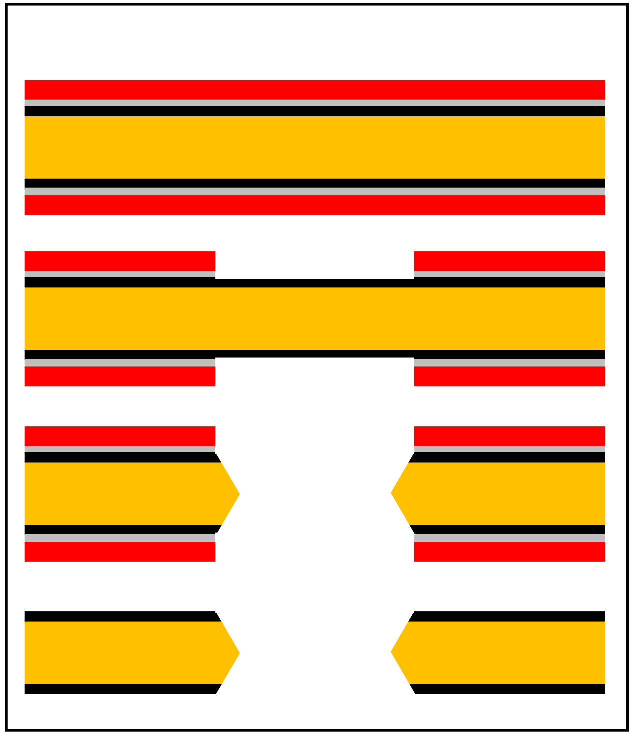
-DLC/Cr/Cu deposition needed for Micromegas high rate detectors and resistive GEM

-Study of strong photocathodes for PICOSEC detectors

-Neutron converter layers deposition like B4C

-Explore other resistive materials like Ge

DLC resistive GEM



Subtractive micro-structuring with chemistry

(Polyimide etching)

Now

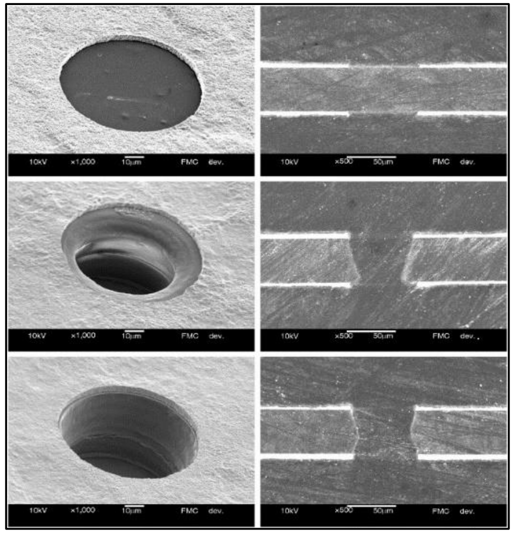
Future

Dead Baths in a dedicated hood with scrubber :
-EDA based chemistry
-Ok up to 1000m2 projects
-Strict safety procedures.

Automatic Horizontal etching line :
-10 000m2 projects.
-Still EDA based chemistry
-We are now finalizing the design (quite complex).
-Could be ready for production next year (2024).
-No more individual protective equipment's (IPE)
-Hermetic machine .
-Less handling → Production cost reduction expected

Laser or plasma subtractive micro-structuring

C02 laser

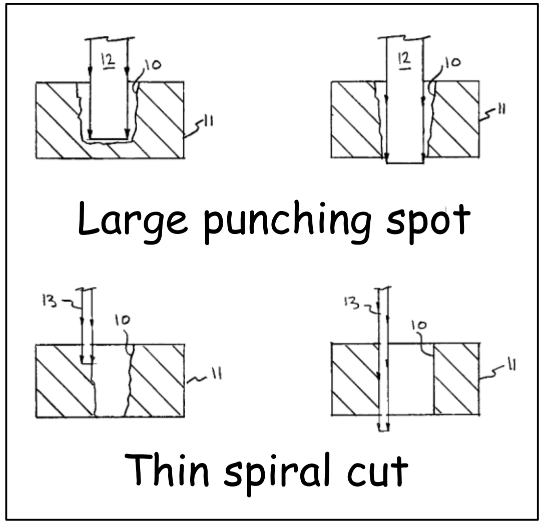


-Many possible base Materials.
-Holes perfectly clean.
-Small patterns

-Limited in size
-Machine cost

Really Interesting

UV laser



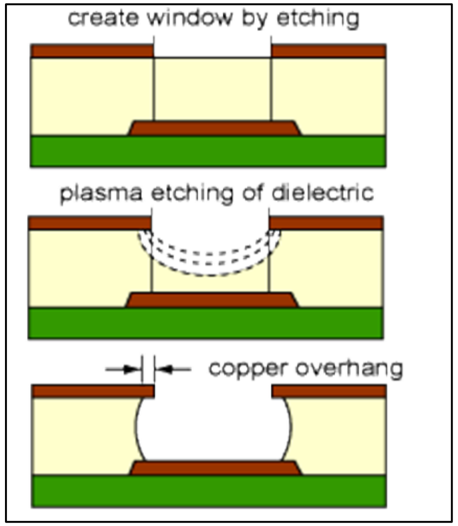
Large punching spot

Thin spiral cut

-Many possible base Materials.
-Machines can drill both metals and polymers

-Too slow! 200 Holes/sec max
-Limited in size
-Machine cost
-Carbonization

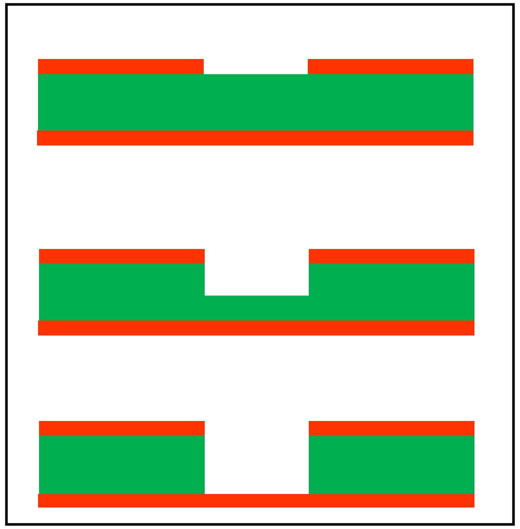
RIE Plasma



-Modarate machine cost .
-Holes perfectly clean

-Not uniform on large size.
-Etching Isotropy too prononced.

DRIE Plasma

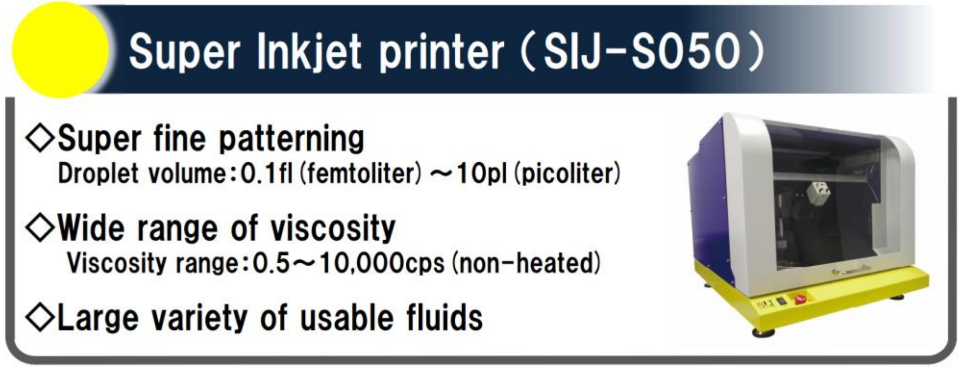


-Perfect cylindrical holes.
-Holes perfectly clean
-Ultra precise patterns

-Sample size : dia 20cm max.
-Machine cost .

Interesting

Additive Micro-structuring ink-jet printers

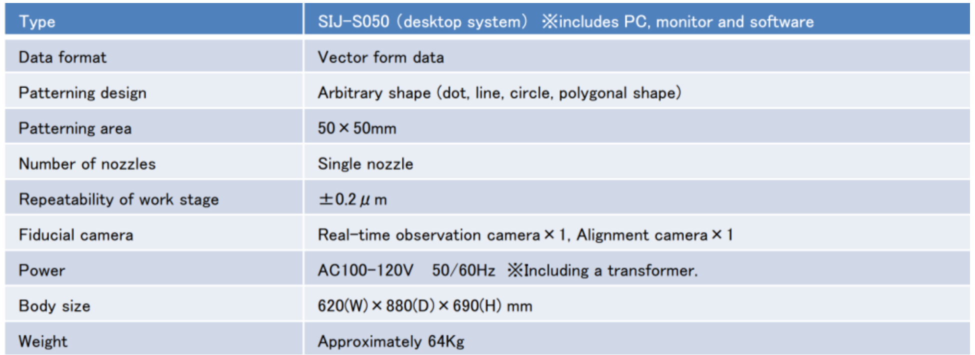


Super Inkjet printer（SIJ-S050）

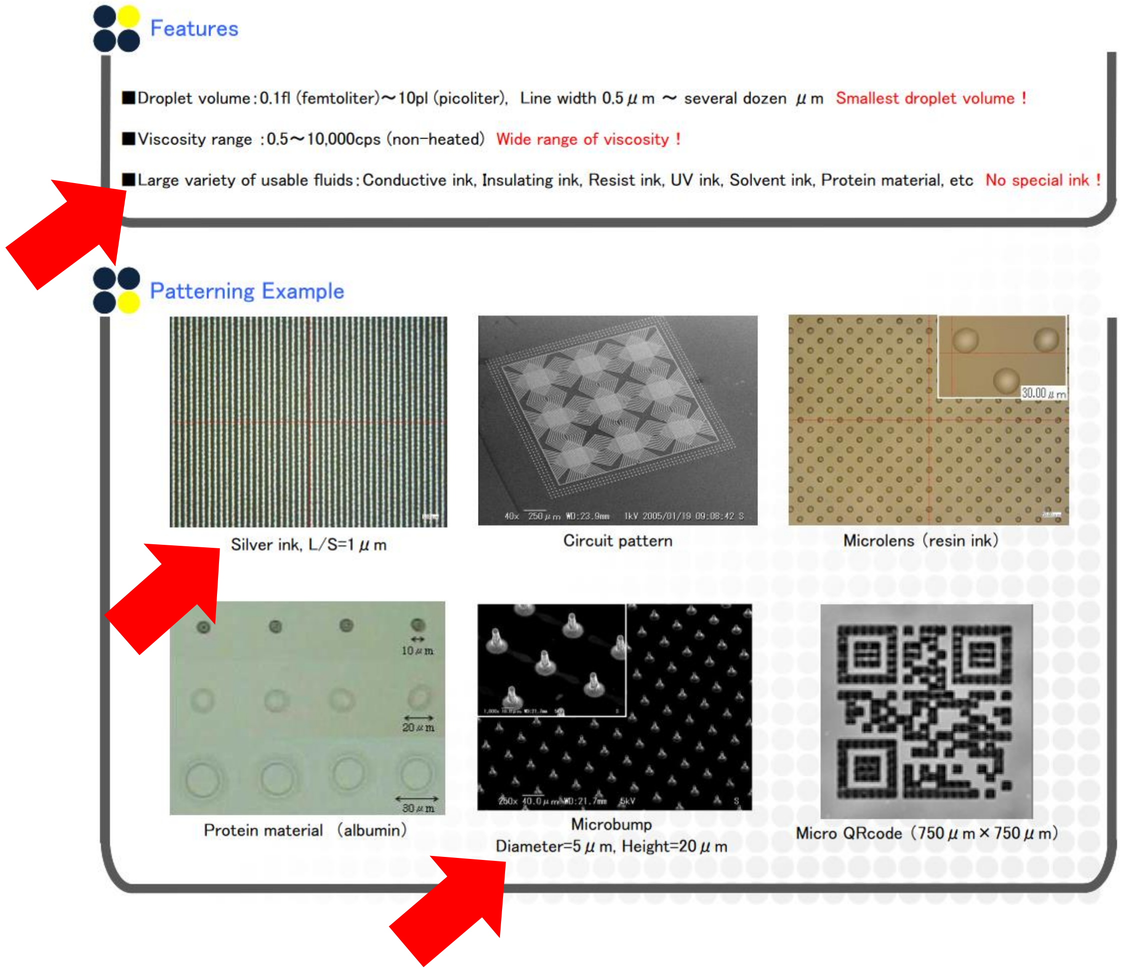
◇Super fine patterning
Droplet volume：0.1fl (femtoliter) ～10pl (picoliter)

◇Wide range of viscosity
Viscosity range：0.5～10,000cps (non-heated)

◇Large variety of usable fluids



Type	SIJ-S050 (desktop system) ※includes PC, monitor and software
Data format	Vector form data
Patterning design	Arbitrary shape (dot, line, circle, polygonal shape)
Patterning area	50×50mm
Number of nozzles	Single nozzle
Repeatability of work stage	±0.2 μ m
Fiducial camera	Real-time observation camera×1, Alignment camera×1
Power	AC100-120V 50/60Hz ※Including a transformer.
Body size	620(W)×880(D)×690(H) mm
Weight	Approximately 64Kg



Features

■Droplet volume：0.1fl (femtoliter)～10pl (picoliter), Line width 0.5 μ m ～ several dozen μ m Smallest droplet volume !

■Viscosity range ：0.5～10,000cps (non-heated) Wide range of viscosity !

■Large variety of usable fluids：Conductive ink, Insulating ink, Resist ink, UV ink, Solvent ink, Protein material, etc No special ink !

Patterning Example

Silver ink, L/S=1 μ m

Circuit pattern

Microlens (resin ink)

Protein material (albumin)

Microbump
Diameter=5 μ m, Height=20 μ m

Micro QRcode (750 μ m×750 μ m)

Many thanks for your attention !